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CAPE OF GOOD HOPE

DEPARTMENT OF AGRICULTURE

TENTH

ANNUAL REPORT

OF THE

GEOLOGICAL COMMISSION

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CAPE OF GOOD HOPE.

DEPARTMENT OF AGRICULTURE.

TENTH
ANNUAL REPORT
OF THE
GEOLOGICAL COMMISSION.

1905.

Presented to both Houses of Parliament by command of His Excellency the Governor.

1906.

CAPE TOWN:
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TENTH

Annual Report of the Geological Commission,

1905.

CONTENTS

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Geological Commission of the Colony of the Cape of Good Hope

1905

MEMBERS OF THE COMMISSION.

The Hon. JOHN XAVIER MERRIMAN, M.L.A.

THOMAS MUIR, C.M.G., LL.D., M.A., F.R.S., F.R.S.E.
Superintendent-General of Education.

SIR DAVID GILL, K.C.B., LL.D., F.R.S., Hon. F.R.S.E.,
His Majesty's Astronomer at the Cape.

THOMAS STEWART, M.I.C.E., F.G.S.

CHARLES CURREY, Under Secretary for Agriculture.

WEBSTER BOYLE GORDON, C.I.E., M.I.C.E., Director of Irrigation.

Secretary—
THEODORE MACKENZIE.

SCIENTIFIC STAFF.

Director—
ARTHUR WILLIAM ROGERS, M.A., F.G.S.

Geologists—
ERNEST H. L. SCHWARZ, A.R.C.S., F.G.S. *(Resigned in June, 1905).*

ALEX. L. DU TOIT, B.A., F.G.S.

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Cape Town,
9th March, 1906.

The Hon.

The Secretary for Agriculture.

Sir,—

I have the honour to forward the Report and Annexures for the year 1905.

The work, as will be seen from the Report of the Director, has made steady progress; though the Commission have felt that it was incumbent on them during the present financial depression to avoid some expenditure which, though useful, could be postponed.

Any such curtailment of the work is a matter of great regret to the Commission, the members being of opinion that the practical value of the survey is such as to warrant increased expenditure instead of less.

It is gratifying to have to record that on several occasions the services of the staff have been requisitioned to advise on the geological conditions of sites selected for municipal reservoirs. The Commission have to express their thanks to the Directors of the S. A. Kerosene Oil Shale Syndicate, Ltd., for permission to investigate the alleged discoveries of Oil Shale at Loeries River, and for the assistance afforded on that occasion.

During the year the staff has been weakened by the resignation of Mr. E. H. L. Schwarz, who has joined the staff of the Rhodes College at Grahamstown. During a service of 9½ years on the staff of the Survey, Mr. Schwarz proved himself an able and intelligent geologist, and the Commission feel sensible of the loss experienced and desire to record their sense of the value of Mr. Schwarz's work.

The forthcoming publication of a Coloured Geological Map of a considerable section of the Colony will, it is hoped, meet a growing demand for information of this nature.

I have the honour to be,
Sir,
Your obedient Servant,
JOHN X. MERRIMAN,
Chairman of Commission.

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GEOLOGICAL COMMISSION.

DIRECTOR'S REPORT FOR THE YEAR 1905.

During the past year a larger area than usual has been mapped. Three geologists were in the field for from two to four months each in different districts during the first half of the year, and after Mr. Schwarz resigned, Mr. du Toit spent three and a half months in Vryburg and Mafeking, and I was in Hay for a similar period.

Through Mr. Schwarz's resignation the staff has been weakened by one third, but until an increased grant is obtained the work can be more satisfactorily carried on by two men than by three, for there is not sufficient money to provide transport and other facilities for three men.

Mr. Schwarz surveyed a strip of country along the coast between the George and Humansdorp Divisions, where the difficulties in unravelling the complicated geological structure of a disturbed region are increased by the presence of thick superficial deposits of comparatively recent date and by the forests. This area is of particular interest on account of the gold-mining carried on there to a small extent, and the possibilities of its further development. It will be seen that Mr. Schwarz comes to the conclusion that the gold-bearing quartz-reefs have not been fairly tested, and that some of the reefs should be worth mining. As to the banket beds there is as yet insufficient evidence of their gold contents. In Mr. Schwarz's Report there will be found much new information about the Pre-Cape, Table Mountain, Bokkeveld, and Uitenhage rocks, and an interesting description of the recent deposits in that unique part of the coast known as " The Lakes."

When I heard that Mr. Schwarz had resigned, I asked him to draw up an account of the area in Tulbagh, Ceres and Worcester surveyed by him in 1896. I did this because a summary only of this work was printed in the

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Annual Report for 1896, and it is desirable to have a longer description of this important area written by the geologist who first surveyed it. Mr. Schwarz most obligingly devoted about a month of his own time to preparing the account which is printed in this Report.

Mr. du Toit was occupied for three months in surveying an area continuous with his previous work in the north-east and lying to the south of it. This area includes the most important part of the only productive coal field in the Colony, concerning which Mr. du Toit has collected and systematised a large amount of information, and he has pointed out the directions most favourable for future development. He describes at some length the curved intrusions of dolerite between Queenstown and Indwe, of which very little was previously known.

During the latter half year Mr. du Toit commenced surveying that part of Bechuanaland which is included in the Cape territories, and his work has proved the existence of highly metamorphosed sedimentary rocks amongst the granite and gneiss; he also shows that the two formations are intercalated owing to the presence of thrust planes, and that the granite is not intrusive as regards these metamorphosed rocks. The latter are overlain unconformably by the volcanic and other rocks (Ventersdorp beds) which lie below the Black Reef beds. There are strong resemblances between some of the metamorphic rocks and the supposed western outliers of the Campbell Rand and Griqua Town series in Prieska, and I now believe that these ridges of magnetic quartzites, etc., in Prieska should be regarded as older than the rocks of the Doornbergen, though their relation to the gneiss round them may not be in all respects similar to that of the northern schists to the Bechuanaland gneiss.

This survey of Mr. du Toit's, in conjunction with mine in Hay, makes an important advance towards the joining up of the geological work done in the Transvaal with that done further south in Cape Colony.

In March I completed the survey of a small area left unfinished in the north of Malmesbury and the south of Piquetberg. From Porterville Road I went by rail to

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Riversdale, thence by road to Uniondale, examining especially some new railway cuttings, the recent deposits near Klein Brak River, and the marine Uitenhage beds on the Knysna estuary. From Uniondale I intended to go by road to the Coega Valley by way of the Baviaan's Kloof, Humansdorp and Uitenhage, but I was prevented from completing this general traverse of the large area surveyed during the past three years by Mr. Schwarz, and had to travel from Uniondale by rail. I was then occupied for over two months in mapping the country between the Zwartkop's River and the Zuurberg, from Enon on the west to Bushman's River. The report on parts of the Alexandria and Uitenhage would have been of more value had Dr. Kitchin's description of the marine fossils of the Uitenhage been available, but his work, which had to be stopped for want of funds a year ago, has only recently been taken up again. A feature of considerable interest in this district is the long line of volcanic rocks, both lavas and breccias, which accompanies the fault separating the downthrown Uitenhage beds on the south from the older rocks of the Zuurberg on the north. I also made an examination into the reported occurrences of oil-shale in the Loerie and Gamtoos Valleys. The reports were ill-founded, and no important results can be expected from the thin lenticles of lignite that have long been known from the Uitenhage beds.

After the Cape Town meeting of the British Association and the geological excursion to the southern Karroo were over, I left for Prieska, whence I crossed the Orange River to make a survey of the Hay Division. This work occupied me till the middle of December. The long drought north of the river made travelling impossible in certain parts of the district, and the absolute lack of veld along the river prevented me from connecting my work with that most interesting piece of country near Ezel Rand, surveyed in 1899. These unavoidable gaps in my map will be filled in during the coming season.

Asbestos digging gives occupation to a considerable and an increasing number of people in Hay; being independent of a larger water supply than that of the average farm, this work will certainly spread widely through

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the district if the market keeps up or improves, for the mineral occurs in several areas not yet worked. Diamond mining is carried on at the Peiser Mine, but the other minerals known to occur in the district, lead and copper ores and gold, have not yet been sufficiently proved for mining purposes. The Prieska railway has increased transport facilities, and there is room for hope that systematic prospecting under these more favourable conditions will bring to light payable ore deposits. There is no prospect, under present conditions, of the good hæmatite iron ores in the north of Hay being made use of.

The work in the Hay Division has proved that volcanic activity played a very important part in that area both before the Black Reef series was laid down, and after the period represented by the Griqua Town beds. Very good evidence was also obtained of the prevalence of glacial conditions in that country during the deposition of the uppermost part of the Griqua Town beds, a welcome addition to the accumulating evidence of cold climates in extremely remote ages. Unfortunately, no further information towards the correlation of these northern rocks with the established European and American Palaeozoic or older beds has been found.

The visit of the British Association in August was an event of no small importance to the Geological Survey. The discussion of many questions relating to South African Geology with geologists of wide experience in Europe and America, and the opportunities of taking them over some parts of the country, were very keenly appreciated, and were of material service to our work.

During the present year a coloured sheet representing the geology of the south-western corner of the Colony on the scale of 3·8 inches to the mile will be published, and it is hoped that other parts of the Colony for which the data are now ready will be similarly treated before long.

The description of Cape fossils collected by the survey has again been taken in hand; the marine mollusca of the Uitenhage beds are being dealt with by Dr. Kitchin, of H. M. Geological Survey, and the mollusca of the Umzamba beds (Upper Cretaceous) by Mr. H.

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Woods, of Cambridge; both of these works may be expected to appear during the year.

The Index to the first eight Annual Reports was issued early in the year to those institutions and persons to whom the Reports were sent.

The following papers by members of the staff have appeared in the Transactions of the South African Philosophical Society:—

"The Glacial Conglomerate in the Table Mountain Series near Clanwilliam," by A. W. Rogers.

"The Rocks of Tristan D'Acunha, etc." by E. H. L. Schwarz.

"The Forming of the Drakensberg," by A. L. du Toit.

"The Volcanic Fissure under Zuurberg," by A. W. Rogers.

A. W. ROGERS,
Director of Survey.

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GEOLOGICAL COMMISSION.

General Abstract of Receipts and Disbursements for the Year ending 30th June, 1905.

	£	s.	d.
To Balance 1st July, 1904	64	6	0
„ Government Grant as per Treasury Drafts	2,000	0	0
„ Balance Account E. H. L. Schwarz	12	10	0
„ Cape Town Council Fees	7	9	10
„ Advances (current) repaid by Vouchers	132	0	0
	£2,216	5	10

	£	s.	d.	£	s.	d.
By Salaries	1,300	0	0			
„ Allowances, Personal	300	11	9			
„ do. Horse	23	19	0			
„ do. Cycle	3	13	0			
„ Railway Fares	36	3	3			
„ do. Carriage and otherwise	18	15	10			
„ Cart, Horse hire, Transport	43	7	0			
„ Postages	13	17	2			
„ Printing Annals, Reports, etc.	47	1	10			
„ Books, Magazines	7	12	9			
„ Analyses	2	16	0			
„ Description of Specimens	60	0	0			
„ Specimen Rock Sections	8	4	6			
„ Compass, etc.	5	9	3			
„ Horse Purchase Loss	20	10	0			
„ Shipping Charges	4	15	8			
„ Wages, Clerical	1	10	0			
„ Furniture, etc.	3	12	6			
„ Miscellaneous	8	5	5			
„ Cape Town Council Fees paid to Staff	13	15	10			
				1,924	0	9
„ Advances made				132	0	0
„ Balance				160	5	1
				£2,216	5	10

I certify that the above Account has been checked and compared in this Department with the Books and Accounts, and has been found to be satisfactory.

Cape Town, 26th February, 1906.

WALTER E. GURNEY,
Controller and Auditor-General.

THEODORE MACKENZIE, Secretary.

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GEOLOGICAL SURVEY

OF

PARTS OF THE DIVISIONS OF UITENHAGE AND ALEXANDRIA.

BY

A. W. ROGERS.

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CONTENTS.

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GEOLOGICAL SURVEY

OF

PARTS OF THE DIVISIONS OF UITENHAGE AND ALEXANDRIA.

BY A. W. ROGERS.

The area surveyed in the Divisions of Uitenhage and Alexandria lies south of the Zuurberg range and between the Bushman's and Zwartkop's Rivers; it includes that part of the Sunday's River valley which lies below the junction of the Bezuidenhout's River.

TOPOGRAPHICAL FEATURES.

The Zuurberg range, which bounds the area on the north, is formed by a group of rounded or flat-topped ridges, trending about east-south-east. They reach a height of 3,244 feet at the beacon, which is placed a few miles north of the limit of the accompanying map.

The contrast between the shape of the Zuurberg range and of the mountains (Great Winterhoek and Elandsberg) in the west of Uitenhage is very great; the latter rise into high peaks, and are greatly serrated, features that are not seen in the gently-curved surfaces of the Zuurberg.

Another contrast, that between the surface of the range and the precipitous valleys cut into it, is remarkable; the valleys of the streams draining the south flank of the Zuurberg have steep grades and very steep sides; precipitous sides also characterise the poort of the Bushman's River, which drains a wide area north of Zuurberg, and traverses the range near Alicedale Junction.

The southern foot-hills, which form a belt about three miles wide, intervene between the main range and the country formed by the Addo Hills and the valleys of the Sunday's and Bushman's Rivers. The foot-hills have rounded summits like those of the main range, but they do not reach the same height.

Longitudinal valleys separate the foot-hills from the country to the south. The Addo Hills lie between the Bushman's and Sunday's Rivers; they are gently sloping, broad hills, with occasional precipitous declivities flanking the two rivers. Their greatest height is about 1,300 feet. On the left bank of the

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Sunday's River the ground rises steeply to the Grass Ridge, a country similar to but lower than the Addo Hills. Between the Coega and Zwartkop Rivers there is a similar tract, called Grass Ridge in the west, and Amsterdam Flats near the coast. The slopes in this country between the foot-hills and the coast are even now largely covered with dense bush, particularly in the Addo Hills, but the hilltops are usually grassy. The southern slopes of Zuurberg and the foot-hills are clothed with forest.

The Sunday's River runs across a wide alluvial plain below the confluence of the White River, and a continuously increasing area in this plain is being brought under irrigation, chiefly by water raised from the river by pumps.

The coast is sandy, and the sand belt reaches a width of over two miles near the mouth of Sunday's River.

At the time of my visit, the Sunday's and Bushman's Rivers alone had water in them, as the great kloofs draining the Zuurberg range were dry.

Geological Structure of the Area.

The Zuurberg range is made up of rather closely-folded rocks, belonging to the Witteberg group; on each flank higher beds, the Dwyka series, come in,[1] though on the south the Dwyka beds are cut out by a fault east of Thornleigh; the range is thus a complex anticline. The strike of the rocks is about E. 10° S. The southern boundary is a fault, along which the Uitenhage beds are thrown down against the older rocks to the north of them. From Duncairn westwards, as far as Enon, a strip of volcanic rocks intervenes between the Uitenhage beds and the older rocks along the fault; from the evidence hitherto obtained, the age of the volcanic rocks must be the same or less than that of the fault, *i.e.*, post-Uitenhage (Lower Cretaceous).

South of the fault nearly the whole of our area is built up of the Uitenhage beds, though these rocks are concealed over wide areas by various thicknesses of comparatively recent limestones, sands, pebble beds, and alluvium.

At Coega Kop an inlier of quartzite, which probably belongs to the Table Mountain series, projects through the Uitenhage beds. It lies on the line connecting St. Croix Island with the Great Winterhoek Mountains, and is doubtless a peak rising from a buried ridge continuous with the Great Winterhoek range.

The recent work in the Sunday's River Valley has not made it necessary to modify seriously the statement in the Report which first dealt with the area,[2] that "the Uitenhage Series in

[1] Pinchin, Q. J. G. S. XXXI. 1875. p. 106.
[2] Ann. Rep. Geol. Com. for 1900, p. 16.

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this district appears to form a shallow syncline, of which we saw one limb along the Zwartkop's River, and the other limb between Enon and Wolve Kraal, in the Sunday's River valley. The axis of the syncline lies between north-west and west-north-west." The northern limb really lies between Enon and Sandflats. The syncline is not symmetrical; the northern limit is greatly affected by the fault along the Zuurberg, while no corresponding feature has been noticed near the Zwartkop's River, and the low dips seen in the exposures of the lower part of the series in that neighbourhood make it probable that a similar southern fault does not exist. In the valleys of Sunday's and Coega Rivers the dips are low, and they vary considerably in direction within short distances.

It is not yet possible to map the marine Uitenhage beds according to fossil zones, though enough is known to show that the beds characterised by certain fossils, if these are on one and the same horizon throughout, do not maintain the same lithological characters over the area examined.

The recent marine beds occupy the tops of the hills over the greater part of the area south of the foot-hills of Zuurberg, and they lie flat on the old surface cut through the Uitenhage formation.

The gravels and alluvia of fluviatile origin lie at various levels below the recent marine beds.

The Table Mountain Series.

The white quartzites of Coega Kop, which probably belong to this series, dip at about 70° to N. 25° E. They have a great similarity to much of the rock belonging to this group west of Uitenhage town.

The rock called St. Croix Island, which lies in Algoa Bay, about four miles from the mouth of Coega River, is probably made of the same rock,[1] and the same can be said of Jahleel and Brenton rocks, near St. Croix, but I had no opportunity of visting the islands.

On the farm Balmoral a group of warm water springs issues from a low hill, of which the rocks are covered up with soil and a ferruginous rock deposited by the spring water. One of the springs, however, issues from between two large masses of quartzite, which appear to be in place, and resemble the quartzite of Coega Kop. The spot lies near a line drawn from the islands through Coega Kop to the Winterhoek range.

[1] According to Dr. Rubidge, quoted by Stow, "The Geologist," 1861, p. 238.

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THE WITTEBERG SERIES.

The Bokkeveld beds do not crop out within this area, though they almost certainly lie under the Uitenhage beds of the Grass Ridge.

The Witteberg beds are seen in the Zuurberg. They comprise quartzites, slaty shales, and sandy slates. The quartzites make great outcrops in the steep valleys draining the mountains, but the shales are rarely seen, except on the roads and railway cuttings. The shales have, however, afforded zones of slight resistance to the streams, and their presence is marked by the steep-sided longitudinal valleys which are a striking feature in that part of the Zuurberg lying between the White River valley and Bushman's River.

The beds are very much folded. Between the south end of the Zuurberg Pass, on Rockwood Estate, and Melkhout Boom there are at least two great anticlines and synclines, with limbs dipping at angles of from 50° to vertical; but there is a great amount of folding on a smaller scale, affecting the limbs of the great folds. The smaller folds scarcely influence the thick bands of quartzite, which reach a thickness of several hundreds of feet; but those portions of the series made up of thin quartzites, interbedded with shales, or shales alone, are often intensely crumpled, as may be seen in the railway cuttings between Sandflats and Alicedale Junction, especially near Bellevue, and in the Bushman's River Poort, near Alicedale.

The strike of the rocks is about 10° south of east on the average.

THE DWYKA SERIES.

From Duncairn in the east to Enon on the west, the Witteberg series is followed to the south by a considerable thickness of greenish and grey shales, whose position proves them to be the Lower Dwyka shales. They are well exposed on the road leading to Zuurberg Pass from Coerney. They usually dip vertically, or at a high angle southwards, or towards S. 10° W. At one spot, on Buffels Kuil, on the right bank of Coerney River, the Lower Dwyka shales dip at a high angle (80°) northwards under the Witteberg beds, and the same dip is seen in the Witteberg beds there, so the rocks are overfolded.

The Dwyka boulder beds have the characters usual to the formation in the south of the Colony. It is a dark, blue-grey rock, with large and small rounded and sub-angular fragments of various rocks in it. These rocks include granite, gneiss, diabase compact and amygdaloidal, quartzites, grits, hard shales, and dark limestone. When the matrix is weathered, just at the top of the steep hill on Rockwood Estate, by the roadside, for example, well-striated boulders can be obtained without difficulty; elsewhere the boulders are difficult to break out.

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The thickness of the boulder beds is quite 1,000 feet, and there is no reason to believe they are partly or entirely reduplicated by folding between Thornleigh and Enon, where each stream flowing south from Zuurberg has cut a deep gorge through the series.

The Upper Dwyka shales were found between Honey Vale and Kremlin; both to the east and west of this strip of country they have been cut out by the fault. The black shales ("white band") are exposed in a small quarry on the road up to Zuurberg, and above these beds there are green shales, thin limestones with fibrous structure, and thin layers of dark chert. These beds are greatly twisted and broken. They are well seen in roadshide quarries and in the water sluit on the road to Zuurberg.

THE UITENHAGE SERIES.

In the Annual Report for 1900, the classification of W. G. Atherstone was adopted for the area between Uitenhage and Geelhout Boom (Dunbrody), on the Sunday's River, with little alteration. It is as follows:

Uitenhage series.	Sunday's River beds. Enon beds. Wood beds.

In the same Report it is shown that this succession is not a strictly chronological sequence over the whole area then known, for strata with marine fossils usually found in the Sunday's River beds are interbedded with red marls and shales, and are overlain by conglomerates like those of Enon in the hill north of the Uitenhage Location. Additional evidence for this conclusion has been obtained during the recent continuation of the work in the Uitenhage district. In spite of this proof that the three divisions into which the series is usually separated are really contemporaneous deposits to a certain extent, so that, except where one member can be proved to overlie another, the lithological nature of either is not a precise guide to its age, it is necessary to retain the three names at least for the purpose of describing the district; and as no large palæontological distinctions, other than that due to the prevalence of marine or fresh-water conditions, have yet been drawn between successive groups of strata, no better classification can be adopted at present.

The fossils from the Sunday's River beds, collected in 1900 and during the past year, have not yet been examined in detail, though the work is now in progress. In the present Report, therefore, the names given to the fossils are those used by

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Tate,[1] with a few corrections kindly given me by Dr. F. L. Kitchin, of H.M. Geol. Survey, who is making an examination of the fossils.

The Enon Beds.

The conglomeratic rocks and the sands and marls interbedded with them are only developed along the northern edge of the area of Uitenhage beds.

Between Slagboom and Enon village there are excellent cliff sections through the conglomerates along the White River. The prevailing colour of the rocks is red, but near Enon village their colour is nearly white. These white rocks are like the white conglomerate of Honing Nest Kloof in Mossel Bay, and the "White Enon" of Willowmore. In the latter district, Mr. Schwarz found that the red conglomerate lay below the white,[2] but in the Uitenhage and Alexandria area the white conglomerate does not appear to form a definite band of rock, for it is not seen on the south of the Slagboom hills, nor in the Coerney River sections, nor in those along the road to Zuurberg Pass from Coerney Station, nor in the neighbourhood of Sand Flats.

On the White River the conglomerate is made of well-rounded and sub-angular pebbles and boulders up to about eight inches in diameter, though the small pebbles are by far the more abundant. In places there are sections from 50 to 100 feet in height cut through the conglomerate, and these show that there is very little sand interbedded with it. The pebbles are often so numerous that they are in contact, and in such a case adjoining pebbles are frequently broken by having been crushed against each other. Neither in these sections nor further east did I find polished pebbles in the conglomerate.

The width of the conglomerate belt is greater near Enon than anywhere between that place and Bushman's River, and it forms a strip of country, about four miles wide, though there are considerable thicknesses of sandy shales and slightly calcareous shales included in this measurement. It is impossible to lay down a consistent boundary line between the Enon beds and the overlying Wood beds throughout a large area, and the apparent absence of fossils from the country between Enon and Sand Flats, probably due to lack of outcrops, prevents the succession there from being compared with the Bezuidenhout's and Sunday's River sections. The only guides to mapping the Enon beds, as distinct from the Wood beds, in this area, were the number of pebbles in the soil and the colour and character of the

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[1] Tate, R. On some Secondary Fossils from South Africa. Q. J. G. S. XXIII, 1867, pp. 139-175.

[2] Schwarz, Ann. Rep. Geol. Comm. 1903, pp. 112-113. The "White Enon" forms a definite horizon in the Oudtshoorn-Willowmore country, lying above red conglomerates which are at the base of the formation.

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latter. Pebbly and reddish sandy soils are characteristic of the Enon areas, and clayey, pale-coloured soils are found in the areas occupied by the Wood beds and Sunday River beds.

The pebbles are chiefly of quartzite and hard sandstone; vein quartz is fairly frequently met with; slaty rocks are rarely seen between Enon and Sand Flats; Dwyka pebbles seem to be entirely absent in the exposures I examined, and there were no granites or other igneous rocks found, nor schists.

On the Zuurberg Pass road the conglomerates are exposed in a roadside quarry, where the matrix is more clayey and less sandy than at Enon. In the Coerney River valley, the conglomerate is seen in a cliff section on the right bank; it is a red rock, with abundant pebbles.

East of Duncairn, on Zand Vlakte and De Bruyn's Kraal, the strip of conglomerate between the Witteberg quartzites and the clayey rocks of the Uitenhage series is very narrow; in this neighbourhood the older rocks are concealed by the comparatively recent sands and marine limestones, but information got from old wells east of the railway proves that the conglomerate does not extend half a mile south of the quartzites, at least within 30 feet or so from the surface.

In places where the conglomerate is thick-bedded, and where no lenticular layers of sand are exposed, it is difficult to determine the dip, but the dip of the strata on White River, the Zuurberg road, Coerney River, Mimosa, the Waggwa road, and on the road from Sand Flats to Bellevue are above 20° to the southward, generally a few degrees west of south, at some places, as on the east end of the Enon ground, nearly south-south-west, and at others (Coerney River and Waggwa) about 10° east of south. Where a series of observations on the same line across the strike of the rocks can be made, as on the road to Zuurberg, and down the Coerney valley, the dip decreases southwards, and is under 10° at distances of three miles or more from the northern boundary of the series. The deep borehole at Sand Flats proves that conglomerates comparable to those of Enon do not occur within 1,500 feet of the surface, though a band of "coarse grey sandstone, containing pebbles,"[1] four feet thick, was passed through at 611 feet, and fifteen feet of "soft grey sandstone, containing water-worn pieces of brown shale,"[1] were met with at 809 feet. The borehole is about 1½ miles from the nearest outcrop of quartzites to the north.

The explanation of the rapid disappearance of the conglomerates eastwards, and the high southerly dips along their northern limit, is evidently that there is a strike fault, with southerly downthrow, on the northern side of the area. The throw appears to increase eastwards, and is probably at its maxi-

[1] **Taken from the record of the bore-hole kindly furnished by the General Manager of Railways, and summarised below, p. 18.**

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mum between the railway near Sand Flats and the Bushman's River. The further course of the fault towards the east has not yet been investigated.

The fault explains the remarkably straight northern boundary of the formation, and the apparently very steep angle at which the Witteberg quartzites disappear under it.

In the Coega valley there is a considerable development of beds without marine fossils, but the only locality where there may be conglomerates of the Enon type in the valley is Balmoral, on the hill from which the mineral springs issue. I am inclined to think, however, that the pebbles which gave rise to the suspicion that Enon beds are present come from the raised beach or river gravels of rather more recent date.

The Wood Beds.

The typical occurrence of this division of the Uitenhage series is along the Sunday's, Bezuidenhout, and White Rivers, in an area which lies just outside that dealt with in this Report, and though the beds must be present, judging from a stratigraphical point of view, south of the conglomerates just described on the flank of the Zuurberg, none of the characteristic fossils were found. There are also certain beds in the Coega valley which apparently pass beneath the marine beds of Sunday's River, and which may be placed in this group.

The Wood beds are not well exposed between Enon and Bushman's River. The small outcrops of marls, shales, and pale-coloured loose sandstones, seen along the roads and a few of the streams, do not afford the opportunity for fossil collecting that there is in the extensive river sections near Dunbrody. The thickness of these rocks between the Addo Hills and the conglomerate to the north must be considerable, but their upper limit is as ill defined as their lower limit (see p. 21). It is certain that the Sunday's River beds, with their marine fossils, take a large part in the structure of the Addo Hills, for they are seen to pass with a low north-easterly dip into the hills from their outcrops on the left bank of Sunday's River, below Barkly Bridge. Rocks corresponding to these marine beds have not been seen on the northern slopes of the Addo Hills, and no useful information was got from the few wells and boreholes on the hills. From wells south of Sand Flats, I was told that shells had been obtained, but the specimens had been lost, and in only one case was it possible to conclude from the information that the shells came from the recent or sub-recent marine deposits which overlie the Uitenhage beds in those parts.

I was told by the foreman in charge of the machine at the deep hole at Sand Flats that a shelly layer had been passed through at 400 feet, but no shells had been kept. As it is

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stated on the record[1] that the rock from 338 to 430 feet was "red shale," it is unlikely that the shelly layer belongs to the marine beds, for so far as the survey has been carried, the beds containing marine fossils are never red; though there may here be an intercalation of marine beds, as at the Uitenhage location.

The Sand Flats borehole passes through shales, marls, and sandstones to a depth of about 1,500 feet, when the boring was stopped. The thin conglomerates have already been referred to p. 17), but they are quite insignificant features. The full record of the borehole, as kept by the foreman in charge, can be seen in the Reports of the General Manager of Railways for the years 1903 and 1904. There is no reason to doubt the determinations of the great bulk of the rocks taken from the hole, for I was able to compare the lowest 200 feet of the core with the record, and found it correct; but there are 6 inches of dolerite recorded from a depth of 1,086 feet, and from experience of other records, wherein the name dolerite is given to hard dark rocks of sedimentary origin, it is impossible to accept the determination in this instance without seeing that portion of the core on which the statement was based. No intrusions of igneous rocks are known in the Wood beds or in any other part of the Uitenhage series in this area, and although it is possible that the "dolerite" recorded is an offshoot from the volcanic belt to be described later, this is not likely, for the volcanic rocks, as seen at their outcrops and in a well, are very different in appearance from the rocks known as dolerite to foremen who have bored in the Karroo region.

The water from considerable depths in the borehole is too salt for use. This salt is derived from the strata pierced below the 800 feet level, for fresh water is obtained above that level, and the surface wells sunk in the recent marine beds in the neighbourhood are not salt.

Along the Coega River, the marine beds of the Sunday's River group crop out on the left side of the valley from the farm Grass Ridge No. 2, down to the mouth. Below these beds there are shales, marls, sandstones, and thin layers of conglomerate, which lie about horizontally or with a slight north-easterly dip. These lower beds do not contain marine fossils, so far as we know at present, and they can be placed more naturally with the Wood beds than with either of the other two divisions of the series, though there is little reason to consider them strictly contemporaneous with the Wood beds of Dunbrody.

On the north side of Coega Kop there are hard brown and grey sandstones, with impressions of lignite and occasional "clay galls" or pellets in them, lying almost horizontally, and evi-

[1] "Report on Water Boring on the Cape Government Railways for the year ending 31st December, 1903." G. 66, 1904.

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dently abutting against the Table Mountain quartzites of the Kop, without the intervention of any considerable mass of breccia or conglomerate. The exposures are not good enough to show the nature of the rock as far as the junction with the quartzite, but there is little room for a change in the rock.

This stone is being quarried for building purposes, for which it appears to be well suited, though the colour is rather dark. It covers but a small area, unless it extends underneath the soil on the other sides of the Kop. It resembles some of the Oudtshoorn sandstones and the rock at Cape St. Blaize more than any other part of the Uitenhage series in this district.

Marls and loose sandstones crop out at intervals up the Coega valley. On Welbedacht's Fontein, on the left bank of the river, near the south-east boundary fence of the farm, there is a good section, showing about 33 feet of these beds. The rocks seen are :—

Recent	Soil and sub-soil	3 feet	0 inches.
	Coarse river gravel	2 „	0 „
Wood beds of Uitenhage series	Red shale	1 „	6 „
	Green marlstone	0 „	6 „
	Red marl	2 „	0 „
	Green marlstone	0 „	3 „
	Red marl	4 „	0 „
	Greenish sandstone	2 „	0 „
	Red marls, with thin partings of green marl, irregularly bedded	18 „	0 „
	Greenish sandstone, with lignite and a few quartzite pebbles	4 „	0 „

The lowest rock is the only one in which any trace of fossils was seen, and the lignite and indistinct impressions of fragments of plant stems found in this rock cannot be determined. Some parts of the sandstones are calcareous; the calcite forms large crystals, enclosing the grains of sand and mutually interfering; large cleavage faces of the calcite are seen when these patches of rock are broken. Gypsum occurs along surface of joints, sometimes filling up the cracks, but I saw none in layers in the rock nor in crystals distributed through it. The red marl and the green marlstone is very like some of the rocks seen in the outlier of Uitenhage beds, through which the Doorn River valley near Heidelberg is cut.

On the farm Balmoral a borehole was put down in the Coega valley to the depth of 200 feet, without reaching the bottom of the Uitenhage series. Those parts of the core kept by the owner (Mr. Hartmann), and shown to me, were rather loose sandstones and marl. Pieces of lignite were not infrequent, and thin layers of that material, half an inch thick, were passed through.

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On Welbedacht's Fontein a borehole has been sunk near the bottom of the valley, some distance up-stream from the section described above. I am indebted to Mr. Ritso, engineer in charge of water-boring, for a copy of the record of the hole, which is of considerable interest, for it proves that 300 feet of sandstones and shales, without thick beds of conglomerate, underlie this part of the valley.

The record gives:—

Surface	to 28 feet...	clays, with pebbles.
28 feet	„ 46 „	shale.
46 „	„ 76 „	shale and sandstone.
76 „	„ 86 „	laminated shale.
86 „	„ 98 „	sandstone.
98 „	„ 144 „	shale.
144 „	„ 150 „	sandstone.
150 „	„ 228 „	shale.
228 „	„ 234 „	sandstone.
234 „	„ 262 „	shale.
262 „	„ 272 „	sandstone.
272 „	„ 300 „	shale.

The distinction drawn between shale and laminated shale probably means that the "shale" is a marly rock, with ill-defined lamination, such as is seen in the natural sections in the neighbourhood. No fossils are noted in the core.

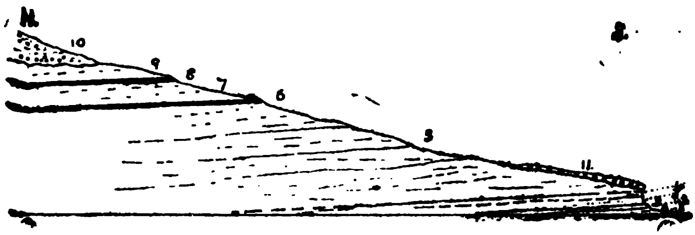

Fig. 1.—Section drawn from the Coega River northwards to the plateau on Zwart Koppen. Scale $\frac{1}{10}$ inch to 10 feet.

1. Grey marl.
2. Thin grey limestones.
3. Greenish marl.
4. Greenish sandstone.
5. Grey shales, marls and clays.
6. Hard sandy limestone with *Exogyra*.
7. Grey shales, etc., with Arca.
8. Limestone with *Trigonia*, *Pleuromya*, *Arca* and *Exogyra*.
10. Marine beach deposits, limestone, pebble beds.
11. River gravels.

On the left bank of the river on Zwart Koppen, about a mile above the main road drift, there are several exposures from the river bed up to the top of the plateau, covered with recent marine beds. The section (fig. 1) represents the succession of rocks at this place. The loose sandy beds and the marls resemble rocks seen further up the valley. The thin limestones in the lower

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part of the section are like those seen in the bed of Sunday's River near Dunbrody, and they contain small pieces of lignite and indefinitely shaped fragments of leaves. Some clayey limestone with these beds has cone-in-cone structure. On the slopes above the low cliff on the river bank there are clays interbedded with thin sandy limestones containing marine fossils, viz., *Cucullaea jonesi*, Tate, *Exogyra imbricata*, Krauss, *Pleuromya lutraria*, Krauss, and *Trigonia herzogi*, Hausmann.

On the right side of the valley, where the road to Port Elizabeth leaves it, there are brown marls with a very few marine shells; the only one I could see well enough to name was a small *Cucullaea*, like *C. jonesi*. Immediately above this marl there is a bed of loose yellowish sandstone, and a similar rock without fossils is exposed in a gully between the main road and the railway. This sandstone must lie below the marls containing *Cucullaea*. Below the railway, on the right-hand shore of the vlei, there are green and grey marls without fossils.

The general dip of the beds in the Coega valley is towards the north-east at a low angle. The dip of the Sunday's River marine beds in the Zwartkop's valley is in the same direction, so if this dip is persistent and if the rocks are not faulted, the marine beds must pass below the Wood beds of the Coega valley, and these in their turn below the marine beds of Sunday's River valley. This is extremely improbable, because the marine beds of Zwartkop's and Sunday's Rivers are very much alike, both lithologically and in their fossil contents, so there must either be a fault, with southerly downthrow, running nearly parallel to the Coega valley and lying south of Coega Kop, or there must be an anticlinal fold between the two valleys. There is no direct evidence at present as to which of these views is correct, but the fault would evidently be a repetition on a small scale of the fault south of Zuurberg. The only visible fault in the Coega valley is seen on the left bank below Welbedacht's Fontein; it has a south-easterly trend, and the rocks are thrown down on the north-east side for a distance of about five feet only. If there is a fault south of Coega Kop its southerly throw may be about 500 feet; the displacement cannot be much less if there is no change of dip in the marine beds to the south.

The Sunday's River Beds.

(a) In the Coega Valley.

(A)[1] The section on the left side of the valley showing the upward passage from the supposed Wood beds, which do not contain marine fossils, into marine beds with *Trigonia herzogi*, *Pleuromya lutraria*, *Cucullaea jonesi*, and *Exogyra imbricata*

[1] The annexed map shows the positions of the sections indicated by capital letters.

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has already been described, and the occurrence of a small *Cucullaea* in the marls on the Port Elizabeth road was also mentioned (p. 22). These beds are the lowest which contain marine fossils, and are exposed in the Coega valley. Whether these beds are later than the Wood beds containing *Psammobia atherstonei, Pecten, Ostrea,* and other marine forms at Dunbrody, it is impossible to state.

There are many exposures of the Sunday's River beds on Grass Ridge No. 1, but they have not been thoroughly searched. The following were seen there:—

Gervillia dentata, Krauss.
Exogyra imbricata.
Trigonia herzogi (small).
„ *tatei,* Neumeyr.

(B). In a kloof nearly a mile north of the hotel at Coega and about 100 feet above the railway station, there are clays, which are used for brick-making, interbedded with hard clayey limestones, from which these fossils were obtained:—

Cucullaea (Arca) jonesi, Tate.
Cyprina rugulosa, Sharpe.
Exogyra imbricata.
Gervillia dentata.
Modiola baini, Sharpe.
Pholadomya dominicalis, Sharpe.
Pleuromya baini, Sharpe.
Ostrea.
Trigonia herzogi (large and small specimens).
„ *tatei.*

These beds are on about the same horizon as those on Grass Ridge No. 1.

(C). In a kloof on the east side of the railway, about a mile up the line from Coega, shales and impure limestones are exposed. The fossils obtained here are:—

Olcostephanus atherstonei, Sharpe.
Astarte herzogi, Goldfuss.
Cucullaea kraussi, Tate (= C. cancellata, Krauss).
Exogyra imbricata.
Gervillia dentata.
Pholadomya dominicalis.
Trigonia conocardiiformis, Krauss.
„ *herzogi* (small).
Neritopsis? turbinata, Sharpe.

Olcostephanus atherstonei is especially abundant in a band of clayey limestone at this locality.

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(D). On the left bank of the river, about half a mile down from the railway, there are exposures of grey clays, shales, and thin limestones, containing:—

Olcostephanus atherstonei.
Corbula ? rockiana, Tate.
Exogyra imbricata.
Gervillia dentata.
Lima neglecta, Tate.
„ *obliquissima*, Tate.
Patella caperata, Tate.
Pecten projectus, Tate.
Pleuromya baini.
Sanguinolaria ? africana, Sharpe.
Trigonia herzogi.
„ *tatei.*

This section includes the beds seen at locality (C) and lower beds.

(E). One and a half miles down the valley from the railway there are grey clays and thin limestones exposed in scars on the steep slope on the left of the Coega estuary; these rocks contain but few fossils, amongst which are:—

Olcostephanus atherstonei.
Cucullaea (Arca) jonesi.
Exogyra imbricata.
Lima neglecta.
Ostrea.

(F). The highest beds seen in the streams which run into the Coega River are probably those exposed in the small kloofs on the west side of the main road to Grahamstown, about a mile and a half from the drift. At this locality were found:—

Cucullaca (Arca) jonesi.
Exogyra imbricata.
Pleuromya lutraria.
Trigonia herzogi (small).

(b) Sunday's River Valley.

This valley was examined from Buck Kraal to the mouth of the river. There are many localities in it which have been somewhat cursorily searched for fossils, but a thorough collection could not be made. The following are the chief places where fossils were obtained:—

(G). The river bed, Buck Kraal. For some 300 yards along the Sunday's River, near Mr. Robertson's house, there are good exposures of rock. The lowest beds seen are thin blue shales

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with large quantities of lignite in small fragments, but no recognisable plant remains were found. These beds are succeeded by false-bedded sandstones and thin layers of conglomerate, yellowish brown in colour, and about 20 feet thick in all; these sandstones do not contain many fossils, but *Trigonia herzogi* and *Psammobia atherstonei* occur in them. They are followed by shales, loose sandstones, and impure limestones in the form of concretionary lumps; the limestone nodules contain many shells, and these can be got in less abundance in the shales and sandstones. Gypsum occurs in cracks and isolated crystals in these beds. The whole section here is about 60 feet thick, and the fossils occur chiefly in the uppermost 30 feet. Those which can as yet be determined are:—

Hamites africanus, Tate.
Astarte herzogi.
Cardita nuculoides, Tate.
Cyprina rugulosa.
Pleuromya baini.
Psammobia atherstonei, Sharpe.
Trigonia herzogi (large and small).
Actaeonina atherstonei, Sharpe.
Turbo baini, Sharpe.

These beds lie above the plant beds of Dunbrody, including those with marine fossils, *Pecten* and *Ostrea.*

(H). The cliff behind Mr. Robertson's house on Buck Kraal is made of shales and thin limestones, evidently lying somewhat higher than the beds exposed in the river. They yielded:—

Hamites africanus.
Astarte herzogi.
Cardita nuculoides.
Pinna atherstonei, Sharpe.
Pleuromya baini.
Psammobia atherstonei.

For some distance below Buck Kraal the rocks are not well seen, and it is impossible to observe their dip, except at rare intervals. The next locality searched is at:—

(I). The cliffs on the right bank on Commando Kraal, where the following fossils were obtained:—

Astarte herzogi.
Gervillia dentata.
Ostrea.
Psammobia atherstonei.
Trigonia conocardiiformis.
" *herzogi.*

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Below this locality, where the beds dip at a low angle (less than 3°) towards north-west, the rocks are not seen again till the Addo outspan is reached[1]; the marls and sandstones on the right bank at this place seem to be unfossiliferous. There is an unconformity in this section; a thick bed of rather loose yellow sandstone lies across the denuded edges of a band of blue sandy clays below.

(K). For a distance of about 300 yards below Addo Drift, sandstones, shales, and thin limestones are exposed on the left bank of the river. Their thickness is about 20 feet. There is much lignite in small pieces in these rocks, and a considerable number of marine fossils, of which the following were determined:—

Cucullaea jonesi.
Exogyra imbricata.
„ *jonesi*, Tate.
Gervillia dentata.
Pecten neglecta.
Pleuromya baini.
„ *lutraria.*
Psammobia atherstonei.
Ptychomya complicata, Tate.
Trigonia herzogi.
„ *vau*, Sharpe.

Following up the road to Uitenhage, some good sections are seen between the river and the Toll-gate. They are chiefly shales and loose sandstones. Several of the outcrops of sandstones are covered with an incrustation of salt, which is sufficiently freely supplied to prevent the usual vegetation growing in the valley bottom at that place. This occurrence of salt is interesting in connection with the source of the salt in the Zwartkops Pan.

(L). Near the salt rock the following fossils were obtained from sandy limestone:—

Cardita nuculoides.
Cucullaea jonesi ?.
Exogyra imbricata.
Ostrea.
Ptychomya complicata.
Trigonia vau.

These beds probably lie about 100 feet above those at locality (K), and they pass under the rocks of Coega Kamma's Kloof and the northern part of the Grass Ridge, for they have a low southerly dip. The higher beds are not well exposed, but they appear on the tracks up to the Grass Ridge, and are greenish sandstones, shales, and hard shelly limestones. Pieces of fossil

[1] This and the next locality (K) are at the place called "Tunbridge's" in Atherstone's and Stow's papers.

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wood, of considerable size, like those found in the Wood beds of Paltje's Kraal[1] are not uncommon, but I could not make a collection of the shells, nor could they be well enough exposed for determination.

From the juncture of the stream in Coega Kamma's Kloof with Sunday's River, down to near the railway at Barkly Bridge, there are many exposures of clays, shales, and thin clayey limestones on the right bank of the river.

(M). On Zoet Geneugd there are precipitous cliffs, which are nearly 200 feet high. At the north end of the cliffs the section (Fig. 2) was obtained; in a steep kloof at this end of the cliffs

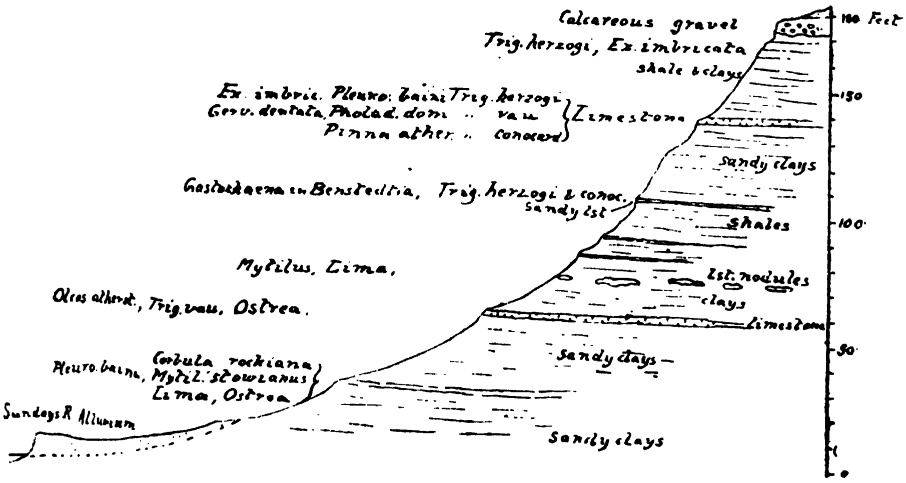

FIG. 2.—Section at the north end of Zoet Geneugd cliffs, on right side of Sundays River.

the individual beds can be examined for many yards along their dip; the face of the cliff is often too steep to work along, owing to the treacherous nature of the shale, but there are numerous steep gullies up which one can climb. The clays and shales are almost without shells, but pieces of lignite are not infrequently seen in them. The shells are confined to the harder layers, sandy limestones, limestones, and the nodules. Some of the limestone is spotted with bits of lignite, and closely resembles the limestone bands in the Wood beds at Dunbrody. The beds in this section include those in the lower part of the Uitenhage road, and they lie above the beds in the river below the drift; they are the lowest beds in the Zoet Geneugd cliffs, though their low southerly dip brings in higher beds very gradually, so that they form the greater part of the cliffs for a considerable distance down the river.

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[1] Geol. Comm. 1900, p. 13.

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The figure (Fig. 2) shows the distribution of the fossils at the north end of the cliffs, and the following is a list of them :—

Olcostephanus atherstonei.
Corbula rockiana, Tate.
Exogyra imbricata.
Gervillia dentata.
Lima.
Mytilus stowianus, Tate.
Ostrea.
Pinna atherstonei.
Pholadomya dominicalis.
Pleuromya baini.
Trigonia herzogi.
 „ *conocardiiformis.*
 „ *vau.*
Gastrochaena dominicalis, Sharpe.
Bensteditia, (?) a plant.

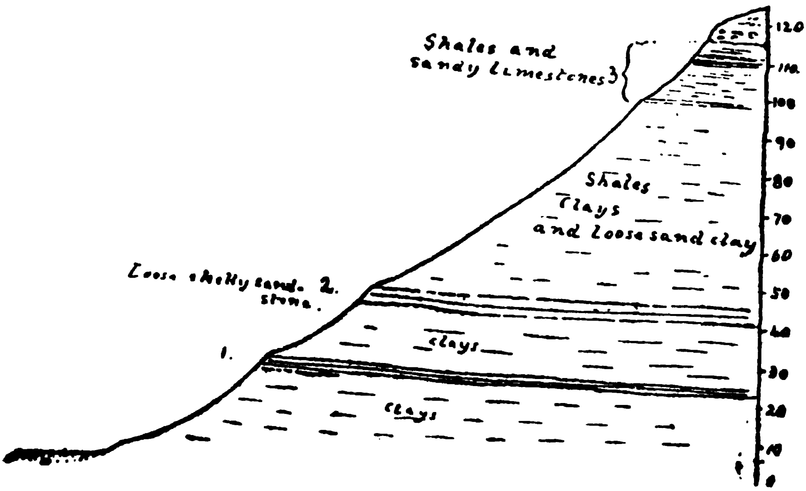

FIG. 3.—Section through cliff on Eb-en-vloed.

A section taken from the broken cliffs on Eb-en-Vloed, just south of the Zoet Geneugd cliffs, will comprise the highest beds of the foregoing section and about 100 feet of the overlying strata. Fossils are more abundant at this spot (N) than on the Zoet Geneugd cliffs, and they seem to be very plentiful as far down as the exposures nearest Barkly Bridge.

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The section in Fig. 3 shows the beds from which the fossils in the following list were obtained:—

1. *Astarte herzogi.*
Corbula rockiana.
Cyprina rugulosa.
Ostrea.
Pinna atherstonei.
Pleuromya baini.
Trigonia herzogi.
" *conocardiiformis.*
" *vau.*

2. *Astarte longlandsiana*, Tate.
Lima obliquissima, Tate.
Trigonia herzogi.
" *vau.*

3. *Olcostephanus atherstonei.*
Astarte herzogi.
Corbula rockiana.
Mytilus stowianus.
Pleuromya baini.
Trigonia herzogi.
" *conocardiiformis.*
" *vau.*
Neritopsis ? turbinata, Sharpe.
Turbo baini, Sharpe.

At the point marked O on the accompanying plan there is a particularly fossiliferous bed high up the cliff, and on a somewhat higher horizon than N. 3., but it does not extend far along the cliff in the same condition, it becomes more sandy and clayey, and has fewer shells in it. The fossils are:—

Cardita nuculoides.
Ceromya papyracea, Sharpe.
Cucullaea jonesi.
Exogyra imbricata.
Gervillia dentata.
Modiola baini, Sharpe.
Ostrea.
Pholadomya dominicalis.
Pleuromya complicata.
Trigonia herzogi.
" *conocardiiformis.*
" *vau.*

In the sandy clays which form so large a part of these cliffs there are many thin shelly layers, crowded with small oysters, and less often with *Ptychomya complicata* and *Lima obliquissima.* These layers disappear within a few feet or yards.

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Lignite is abundant in both the clays and the harder beds; pieces eight inches long are not uncommon. In the big kloof on Ebb-en-vloed prospecting has been done on a thin layer of lignite, but it thins out within five feet of the outcrop on the kloof side. This lignite is in the clays and shales between 2 and 3 in Fig. 3, and if it were of any constancy it would crop out in the cliffs to the south-east.

The lignite appears to be in every way identical with that which occurs in the Wood beds. A sample from Eb-en-Vloed, analysed by Mr. J. G. Rose, Government Analyst, gave the following result:—

Moisture	10.41%	
Ash	14.80 „	
Volatile matter	42.40 „	(includes moisture and sulphur).
Fixed carbon	42.30 „	
Sulphur	5.90 „	

The sulphur is present in greater quantity than is usual in a substance of this nature, and the following analysis of the ash, also by Mr. Rose, shows that it probably exists, in combination with iron, as pyrites or marcasite:—

Silica and gangue	18.73%
Iron and aluminium oxides	64.06 „
Lime	3.43 „
Magnesia...	.34 „
Alkalis, chlorine, etc. (by difference)	13.44 „

The structure of the wood can be seen on broken surfaces of some pieces of the lignite.

On the farm Olifant's Kop there is a richly fossiliferous zone, rather higher than half-way down the steep slope to the river; the fossils occur in clayey limestone chiefly. The following species were collected there (P):—

A macrurous (cray-fish-like) crustacean.
Astarte herzogi.
Cardita nuculoides.
Ceromya papyracea.
Hamites africanus.
Modiola baini.
Pinna atherstonei.
Pleuromya baini.
Trigonia conocardiiformis.
„ „ (a related species).
„ *herzogi.*
„ *tatei.*
„ *vau.*
„ *ventricosa.*
Small gastropods.

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These beds almost certainly lie upon the highest fossiliferous rocks of the Eb-en-Vloed cliffs. They dip at about 4° to the south.

The next outcrops down the river are on the left bank, 500 yards below Barkly Bridge, where there are yellow sandstones, with *Trigonia ventricosa*, Krauss.

From Barkly Bridge to Colchester the exposures are very poor, though they can be found on the bushy slopes on Fascadale, Ingleside, and Klein Vetmaak's Vlakte; on Fascadale outcrops of sandy limestone, with *Pleuromya baini*, *Astarte herzogi*, and *Ostrea*, appear at the surface about half-way down the slope, below the outcrops of the raised beach deposits.

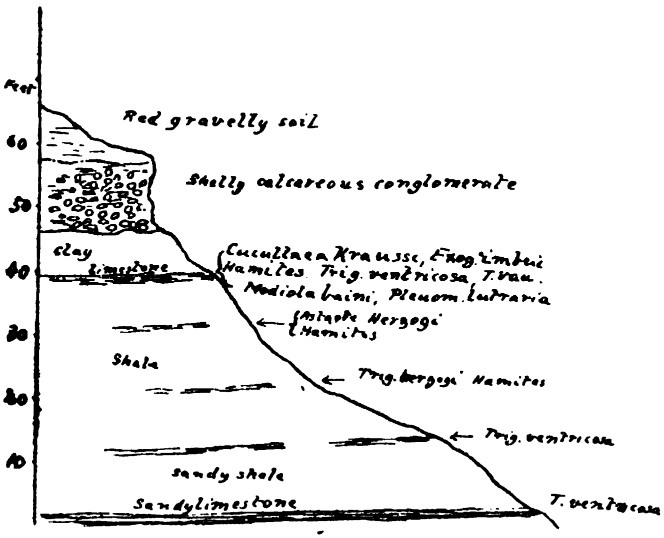

FIG. 4.—Section in kloof behind Colchester.

On account of the absence of good exposures below Barkly Bridge it is difficult to ascertain the position of the fossiliferous rocks behind Colchester (a small village on Vetmaak's Vlakte, on left bank of Sunday's River), with reference to those elsewhere.

North-east of Mackay Bridge, by which the Grahamstown road crosses Sunday's River, there is an exposure of 70 feet of unfossiliferous clays, and these pass under the fossiliferous beds in the kloof behind Colchester. Somewhat over 50 feet of clays, with thin limestones interbedded with them, are to be seen

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here (Q). The section (Fig. 4) shows the distribution of the fossils, which include the following species:—

Hamites africanus.
Astarte herzogi.
Cucullaea kraussi.
Exogyra imbricata.
Modiola baini.
Pleuromya baini.
„ *lutraria.*
Trigonia herzogi (large and small forms).
„ *vau.*
„ *ventricosa.*

This locality is near that called "McLaughlin's Bluff" by Stow,[1] but I could not identify the spot. The hill sides have doubtless altered in outward appearance since 1870, when the sketch on p. 500 of his paper was drawn, by the increase of low bush. The list of fossils from his locality given in Fig. 3 of his paper is not identical with the above, but there are several common to the two.

About half a mile nearer the mouth of the river there is a good exposure near the top of a side gully, near the end of the big kloof up the south-east side of which the road to Grahamstown is carried. At this place (R) the following fossils were found:—

Belemnites africanus, Tate.
Astarte herzogi.
Pholadomya dominicalis.
Trigonia vau.
„ *ventricosa.*

The most remarkable feature here is the extraordinary abundance of *Trigonia ventricosa*, though other shells are not very numerous, and the collection is small in number of species. These beds are probably on a slightly horizon than the uppermost Uitenhage beds in the kloof behind Colchester.

There are many described species of mollusca and three cephalopods, known from the Uitenhage beds, which are not included in the above lists, for they were not found. There were several other mollusca and one cephalopod found, but not mentioned, because they have not yet been determined; they may be new species.

So far as the collections yet made give any evidence on the matter, it would appear that the beds exposed in the Coega and Sunday's River valleys cannot yet be subdivided into zones characterised by particular fossils.

[1] Stow, Q. J. G. S. Vol. XXVII. pp. 497-522.

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The highest beds exposed are probably those near locality (P) on Olifant's Kop, and a comparison of the fossils found there with those in the river section at Buck Kraal shows that there is little difference between them; the Olifant's Kop beds yielded more species of *Trigonia*, but the Cephalopod *Hamites africanus* is common to both.

It is to be noted, that at Wolve Kraal, a little further up the river, in beds that are probably on the same horizon as the Buck Kraal sections, both *Trigonia vau* and *T. concocardiiformis* occur in addition to *T. herzogi*.[1]

The Buck Kraal section is probably the lowest of those described here from Sunday's River above Barkly Bridge. The rocks in this valley were probably formed rapidly. The sandy muds and limestones contain a large amount of lignite, which was drift-wood carried down by the rivers, water-logged, and quickly buried under the accumulating sediments.

THE ZWARTKOPS SALT PAN.

In the neighbourhood of the salt pan there are no good exposures, though some shales and a band of limestone crop out on the north and north-western banks. In these beds *Trigonia vau* and a small form like *T. herzogi* occur (locality S on the plan). Stow[2] mentions the occurrence of echinoid spines, *Ostrea* and *Turritella*, as well as of *Trigonia*, at this place, and considers that the salt which is deposited in the pan comes from the salt contained in beds overlying those in which *Trigonia* occurs, but belonging to the same series, and representing material deposited in basins cut off from the open sea[3] In another place the present writer expressed the opinion that the salt must be derived from the strata overlying the Uitenhage series,[4] but having seen the salt incrustation on the sandstones exposed along the Uitenhage road near Addo Drift (p. 26), I believe Stow was right in tracing the origin of the salt to the Uitenhage beds. The fact that the salt beds above Addo drift must crop out on the Zoet Geneugd cliffs, though their outcrops there are not incrusted with salt, shows that the salt is local.

A borehole in the neighbourhood of the salt pan penetrated clays, sandstone, and blue shale to a depth of 94 feet.[5] There were no parts of the core available for examination, but it is probable that the "sandstone" of the record is really a calcareous rock like the sandy and clayey limestones of the Zwartkop's and Sunday's Rivers.

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[1] Geol. Comm. 1900, p. 16.
[2] Stow, Q. J. G. S. Vol. XXVII. p. 505
[3] *Loc. cit.* p. 514.
[4] Introduction to Geology of Cape Colony, 1905, p. 386.
[5] Information kindly given me by Mr. Engleberg at the salt pan.

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Gypsum occurs in the form of crystalline plates about the size of a shilling in the sandy mud in the floor of the pan; it is evidently thrown down from solution.

The Volcanic Rocks.

The northern limit of the Uitenhage beds, as we have already seen, is a fault. Where these beds abut against the Witteberg formation, on Duncairn and to the east of that farm, the southernmost part of the quartzites is shattered. On the road from Sand Flats to Waggwa conglomerates of the Enon type, underlain by red sands, are seen dipping at an angle of about 20° to the southwards, and the Witteberg beds crop out a few yards to the north. There is a thickness of about 20 feet of breccia, made up of angular fragments of quartzite set in a sandy matrix, north of the Enon conglomerate; but the outcrops show a gradual passage from the breccia, which is evidently broken up quartzite with a matrix of the same rock finely comminuted, into the solid unbroken quartzite within a distance of some 30 yards. The nature of the fragments and matrix of the breccia make that rock easily distinguishable from the Enon conglomerate.

On Duncairn the volcanic rocks first appear, and they lie between the southernmost outcrops of the Witteberg quartzites and the Enon conglomerate. The quartzites here also are brecciated in the same way and to about the the same degree as on the Waggwa road. From Duncairn the volcanic rocks are known to extend westwards as far as a point behind Enon Missionary Station, a distance of 19 miles; how much further they appear at the surface is not known.

The manner in which the volcanic belt begins on the east is not clear, as the ground is covered with soil and thick vegetation, but it must swell rapidly to a width of about 600 yards. The rocks composing the belt here are amygdaloidal lava, more compact lava, and grey and pink tuffs. It was impossible to trace out the boundaries between the tuffs and the lava, but the lava contains many fragments of tuff, and in part, at least, behaves towards the tuff as an intrusive rock. The tuffs are fine-grained rocks, which look more like fine-grained argillaceous sandstones than volcanic tuffs; their constituents are too small to be determined with the aid of a lens only, but they are probably of the same nature as the similarly coloured tuffs from the same fissure further west.

The lavas are reddish rocks, with a compact dull matrix, in which felspar laths are often visible under a lens; other original constituents are probably present, as in the similar rocks to the westwards, to be described below; the lava contains many small irregularly shapel drusy cavities and rounded steam holes. These holes and the drusy cavities are sometimes lined with a thin

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layer of minute pale green crystals, which have not been determined; others are partly or wholly filled with chalcedony, or with chalcedony and quartz crystals; others again are filled with a zeolite, heulandite, and a few with calcite. A borehole has been put down in some red tuffs within half a mile of the east end of the belt, and down to a depth of 250 feet the rock seems to have been of more or less the same nature throughout, judging from the information given me by the owner of the farm.

About a mile west of the east end the volcanic belt widens out to over half a mile, and is divided into three zones by the presence of an elliptical area of breccia and tuff situated on the divide between kloofs running eastwards to Duncairn and those descending westwards to Thornleigh (part of Mimosa). The general relations of the rocks at this locality are shown in Fig. 5,

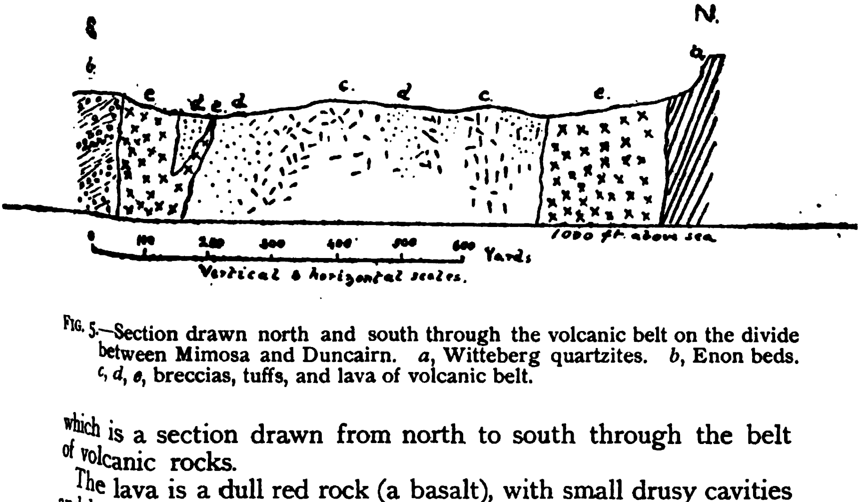

FIG. 5.—Section drawn north and south through the volcanic belt on the divide between Mimosa and Duncairn. *a*, Witteberg quartzites. *b*, Enon beds. *c*, *d*, *e*, breccias, tuffs, and lava of volcanic belt.

which is a section drawn from north to south through the belt of volcanic rocks.

The lava is a dull red rock (a basalt), with small drusy cavities and larger steam holes, though in places it becomes more compact by the decrease in the number of these spaces. Under the microscope the base [1357-1359] is opaque, owing to the amount of rusty iron oxide present, but very minute crystallites, perhaps of felspar, are scattered through it. In this matrix there are abundant grains of augite, which very rarely have one or more straight boundaries, and various sized crystals of a basic plagioclase, some of which is labradorite. Some of the plagioclase crystals have different properties in different parts; the change is very gradual and regular from within outwards. Olivine is absent from the two sections cut. The steam holes and drusy cavities are filled with a zeolite, chalcedony, chlorite, and a nearly isotropic mineral, which is probably analcite. The felspars are considerably altered, and the augite is frequently stained red, like the opaque base, but to a smaller extent. The larger felspars are often packed together, and appear to be

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rather large porphyritic crystals before the various individuals in the lump are distinguished; there is no sharp distinction between these larger individuals which may be thus grown together and the smaller individuals, for there are many crystals of intermediate sizes.

On the south side of the mass of tuffs and breccias the basalt forms small dykes in the fragmental rocks, which are distinctly hardened near the contact, and have both irregularly shaped and rounded cavities, partially or entirely filled with chalcedony and quartz. A section [1358] from a junction of the lava and tuff shows that the latter rock is made up of small angular fragments of quartz, felspar, a few pieces of augite and dark mica, and small bits of opaque red rock, which is evidently derived from the ground mass of the lava[1]; these fragments are in a ground mass which is partly chalcedony and partly dusty matter, whose nature is uncertain. The lava in this slice is not different from the basalt obtained at a distance from the tuff; it shows no signs of chilling, such as a greater amount of amorphous base or a more pronounced porphyritic structure.

On the path which leads through the bush in the kloof on the north-east corner of Thornleigh (Mimosa) there is a coarse breccia, containing subangular pieces of reddish chalcedony or chert as much as an inch in diameter. This breccia was seen, in small outcrops and loose fragments only, between lava on the south and the Dwyka series on the north. It undoubtedly belongs to the volcanic group; there are the more usual fine-grained tuffs in the immediate vicinity, and a coarse breccia with very similar characters occurs along with the tuffs in the neck to the east, though chert fragments were not noticed in the latter rock.

The basalt form a wide strip, passing south of the tuffs described above, and makes a ridge sloping westwards to the main kloof on Mimosa. At the place where two kloofs join to form the main valley there is a small area of buff-coloured and pink tuffs, the lava lies to the south and the Dwyka boulder beds to the north. This seems to be a small neck, like the breecia and tuff neck already described and the one on the Nieuw Post road, to be mentioned below.

There is a rather large lava outcrop in a garden situated in the Mimosa valley at the end of the lava ridge, and there are bands of more and less amygdaloidal rock running across the outcrops dipping about 20° to S. 10° W. There are also irregular layers of pipe-amygdaloid at this spot. The

[1] In a description of the "Volcanic Fissure under Zuurberg" in Trans. S. A. Phil. Soc., Vol. XVI. Part 2, p. 193 it is stated that "pieces of lava do not occur in the fragmental rocks" of the group. This is a misstatement based on inspection of specimens alone. Thin sections of the red and pink tuffs show innumerable minute bits of lava; the light coloured tuffs are nearly free from them, though some lava fragments are seen in these also.

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pipes are perpendicular to the layers. The bands of various textures are not definitely separated from each other, but are parts of one rock mass. Fragments of pipe-amygdaloid were seen again near the boundary between Duncairn and Mimosa, but not in place.

The old road from Mimosa to Nieuw Post ascends the escarpment by means of the divide between the streams which run into the main valley on Mimosa and those which join the Coerney River. Immediately south of the Witteberg outcrops there is a tract of ground in which the underlying rock is concealed, but a considerable variety of fragmental rocks, belonging to the volcanic group, crop out southwards of this doubtful area. It is possible that a part of the Dwyka series, which is first met with west of the neck on the Duncairn-Mimosa boundary, occurs here also, but this is not likely, and it is very improbable that any part of the Dwyka boulder beds is present at this spot. A section through the volcanic belt is given in Fig. 6, which shows

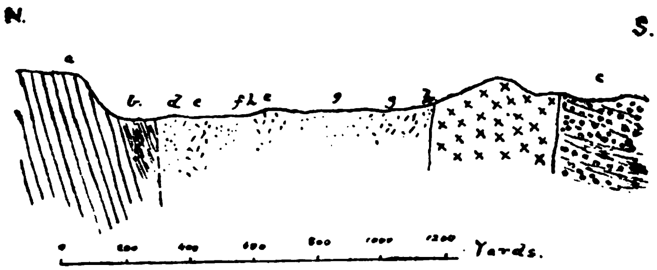

FIG. 6.—Section through the volcanic belt on Mimosa. *a*, Witteberg beds of the Nieuw Post escarpment. *b*, Lower Dwyka shales—possibly present. *c*, Enon beds. *d*, brown sandy micaceous tuff. *e*, breccia. *f*, green tuff. *g*, red and light coloured tuffs. *h*, pink tuffs.

the succession of varieties of rock in the belt along a certain line. The main point is the occurrence of a large mass of breccia and tuffs of various kinds in a locality where the band of volcanic rocks swells out to more than its usual width. A thick band of lava separates the fragmental rocks of this neck-like expansion and the conglomerates and sands of the Uitenhage beds to the south.

The rocks at this place are not well exposed, but several specimens were taken from outcrops that barely rise above the ground on the cattle-track itself; off the track outcrops are still less frequently seen in the bush, which is quite luxuriant on the steep hill sides south of the Zuurberg.

The brown micaceous rock, which is the northernmost exposed member of the volcanic group, looks not unlike a rather soft sandstone. It has circular green spots on its surface, evidently sections through spherical patches of a green tuff like

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that described below. Under the microscope a section of this brown rock [1348] shows more or less angular and uniformly sized grains of quartz and plagioclase felspar closely packed together, a few flakes of mica and grains of zircon. The matter between the grains is indeterminable, but it is chiefly made of very minute brightly polarizing flakes.

There are many outcrops of a breccia with a pale yellowish brown matrix, containing a few pieces of quartzite and kaolinised felspar, and very many more or less rounded lumps of a brownish substance, which in the hand specimens seems to differ in colour only from the paler matrix. In thin section [1349] small fragments of a granitic rock, consisting of quartz and felspar, are seen, in addition to the quartzite and altered felspar. The matrix is composed of chips of quartz, microcline, plagioclase, and zircon set in a base of very minute fragments; the base as a whole is isotropic. There are rounded areas, in which the proportion of base to quartz and other chips is greater than elsewhere, and in which the base is yellower in colour by transmitted light. These areas are the darker patches in the hand specimens, and they are evidently pellets embedded in a matrix of very similar nature.

Another section [1350] taken from a different outcrop of this type of breccia shows grains of garnet and green hornblende in addition to the minerals mentioned above. There is also some chalcedonic silica in this rock, playing the part of matrix in certain portions of the slide.

In the green breccias thin sections [1351, 1352] show that the colour is given by the abundance of weakly, doubly refracting flakes of a chloritic mineral in the matrix. In other respects there is no appreciable difference between the green rocks and the brownish or yellow tuffs.

A section through one of the red tuffs [1353] reveals a great difference between these and the other fragmental rocks; the chips of quartz and felspar are accompanied by innumerable small particles of deep brown or reddish glassy matter, with angular or rounded boundaries. These are evidently pieces of lava, and they contain small steam holes or amygdales, small felspar laths, and pseudomorphs, often small crysals of olivine and augite. The felspar laths have low extinction angles, and appear to belong to a more acid variety of plagioclase than one expects to meet with in olivine basalts.

The lava on the south side of the fragmental rock is a close-grained red rock, with many steam holes, filled with calcite, analcite, heulandite, chalcedony, and other minerals. A section from the rock exposed on the ridge south of the tuffs [1355] has a ground mass which is almost opaque, and is composed of microlites that are scarcely translucent, owing to the amount of dusty matter in them. These microlites are surrounded by opaque red particles, hydrated oxide of iron. Plagioclase

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crystals lie in the ground mass, but they are usually altered to a considerable extent; the extinction angles about the planes of twinning point to their being oligoclase. Small, but quite fresh augite crystals and serpentinised olivines are the other porphyritic constituents.

West of the neck-like expansion of the volcanic belt on the Nieuw Post road the lava forms a band over 1,000 yards wide, out of which a valley and a ridge trending westwards towards Coerney River have been cut.

Where the Coerney River traverses the belt the width of the latter has decreased very greatly, and the only rock belonging to it exposed near the river is a coarse quartzite breccia, with much calcite in the matrix. This breccia appears in the river bed over a distance of about 100 feet, and these outcrops are rather far from the nearest outcrop of the Enon beds down stream, while 30 yards of concealed rock separate them from the southernmost Dwyka exposures up stream. The lava in the valley and ridge to the east of the river varies considerably in texture from place to place, according to the abundance and size of the steam holes, and there are patches of red and yellowish tuffs associated with it, but it retains the same general characters as it has further east.

West of the Coerney River there is only a narrow strip of lava present, and it was not followed continuously along the three miles of bush country to the valley on Rockwood, where it is exposed on the road to Zuurberg. At this locality the relationship of the lava to the sedimentary rocks north and south of the fault is most clearly seen, though at the time of my visit the actual junctions were not exposed. It is very probable, however, that the contacts may be seen after unusually heavy rains or when a particular section of the road is being repaired.

The road from the mountain goes down the right-hand side of the valley in such a way as to traverse the Upper Dwyka shales, the volcanic belt, and finally the Enon beds. The Upper Dwyka shales are highly disturbed, twisted, and traversed by small faults where they are seen in the roadside quarry and ditch nearest to the volcanic rock. The volcanic rock is at this place a highly amygdaloidal lava, red in colour, with a rather peculiar appearance, owing to the abundance of heulandite and its pearly lustre on the basal cleavage faces. The rock itself is a basalt like that at Duncairn and Mimosa. Near the bed of the stream, where it crosses the volcanic belt, a well has been sunk on the lava. The rock from the top of the well is just like that seen by the roadside, but from lower down a dark-coloured, heavy rock, with steam holes filled with a black soft substance, has been taken out; under the microscope the latter is seen to be a serpentinous mineral. The difference in colour between this rock and the similar basalt of the outcrops seems to be due to the production of red hydrous oxides of iron in the ground mass of the rock at the surface.

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The nearest outcrop of Enon beds is about 100 yards down the road from the lava, though owing to the low angle at which the road crosses the boundary between the two rocks, the Enon beds exposed in the small road-metal pit must be within 20 feet or so of the lava. The Enon beds here consist of red conglomerates, and the dip is southwards at 35°. Further down the road towards Coerney Station the dip of the variously coloured marls decreases considerably.[1]

From the Zuurberg Pass road the volcanic rocks were followed up the ridge to the northern part of Kremlin, across Slagboom to the White River, and behind the conglomerate hills on Enon Mission Station. Throughout this range of nine miles tuffs appear to take a small part in filling the fissure, but there are several outcrops of tuffs and breccia on Kremlin and Slagboom. Generally, the exposures are too few to allow the relation of the lava to the tuffs to be ascertained, but on the cattle track from Slagboom to the Zuurberg road the lava is seen to penetrate the tuffs in the form of veins or small dykes.[2]

The width of the volcanic belt where the Zuurberg road crosses it is about 100 yards, but it swells out to 300 on Kremlin, and 800 on Slagboom. On the latter farm the course of the fissure turns towards the north-west, where it is crossed by the White River, and then turns back again to nearly due west. The trend of the Dwyka series does not take a correspondingly large turn, and the upper shales are not met with far west of the boundary between Kremlin and Rockwood Estate. On Slagboom the volcanic rocks are seen to be in contact with the Dwyka boulder beds on the north.

Where the White River has cut through the volcanic rocks the latter are seen to occupy a vertical or nearly vertical fissure. The height of the top of the volcanic ridge on Slagboom is about 800 feet above the river, and on looking westwards across the valley one can see the volcanic rocks, with the Uitenhage beds to the south and the older rocks to the north, very clearly. On the Zuurberg Pass road the same relation can be made out, but not so obviously as in the valley of the White River, because the section is less extensive.

The Nature and Origin of the Volcanic Belt.

The fact that a fault exists along the northern boundary of the Uitenhage formation in this area has already been pointed out. It is obvious from the foregoing description and from the map that the volcanic rocks coincide in position with the fault;

[1] A section through this part of the belt is given in Fig. 1. on p. 192 of Trans. S. A. Philos. Soc., Vol. XVI., 1905.

[2] A plan of these outcrops is given in Fig. 2, p. 192 of the paper cited above.

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they lie between the Uitenhage beds on the downthrow side of the fault and the Dwyka and Witteberg formations on the upthrow side.

The absence of the Dwyka series on Duncairn and east of that place, the cutting out of the boulder beds and probably also of the Lower shales on Mimosa, the elliptical outcrop of the Upper shales near the Zuurberg road and its disappearance on Kremlin prove that the volcanic rocks do not follow the Dwyka series conformably.

It might be held that the volcanic group came into existence after the Dwyka and older rocks had suffered extensive denudation, but before the Uitenhage beds were deposited. There are great difficulties in the way of accepting this view; for no fragments of lava or tuffs have been recorded from the Uitenhage beds, although the lava is a very conspicuous rock, and the conglomerates have been examined with the object of finding lava pebbles at all the available exposures between Enon and Bushman's River; the Coega valley conglomerates have also been carefully looked at, though before the existence of the volcanic rocks was known. The lavas and tuffs have evidently never been subjected to the movements and pressure that brought about the incipient cleavage and the folding of the rocks in the Zuurberg.

There is no evidence of the intercalation of the lava with the lowest of the Uitenhage beds, nor have volcanic rocks ever been found interbedded with this formation elsewhere in the Colony.

There seems to be no other explanation than that adopted when the belt was being examined, that the volcanic rocks rose along the line of faulting during or after the production of the fault. This explanation does not account for certain facts, the presence of a band of pipe-amygdaloid in the Mimosa valley, where the "pipes" are arranged perpendicularly to a plane which dips about 20° towards S. 10° W., and the existence of a band of scoriaceous lava parallel to the pipe rock.

The lava does not resemble closely any previously described Colonial rocks, but it is more like some of the Drakensberg lavas than any other volcanic rock in the Colony.

In Willowmore[1] there is a broad band of shattered rock, quartzite of the Table Mountain series, on the north side of the faulted outlier of Enon conglomerate of Baviaan's Kloof. This shattered belt is three-quarters of a mile wide. Broken rocks are often found in connection with normal faults, but brecciation on this scale is not to be accounted for in the same way as the more limited masses of breccia along ordinary faults.

* Schwarz "Ann. Rep. Geol. Comm. for 1903, pp. 132-3.

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It is permissible to look upon these bands of broken rocks as having been produced by explosions of the kind that gave rise to the remarkable breccias of Swabia, elaborately described and discussed by Professor W. Branco.[1] There is one important difference between the two regions. Professor Branco shows that the Swabian explosions took place quite independently of structural features, such as faults, and that they are closely resembled by the Kimberley pipes of South Africa, but in the Zuurberg region the explosions took advantage of an existing line of weakness or faulting.

Whether the explosions took place during or after the movement along the fault is a difficult question to settle.

In connection with this belt of volcanic rocks it is interesting to notice that its occurrence may have been partly responsible for the old view that the Dwyka boulder beds were of volcanic origin. A. G. Bain, Atherstone, and Pinchin knew this district, and their visits to the foot hills of Zuurberg are remembered by at least one of the old residents, Mr. Walton, of Mimosa. The volcanic rock, as is evident from the map attached to this Report, replaces the Dwyka to a certain extent, *i.e.*, it occurs on the same line of strike. Atherstone, in his well-known paper, entitled "Geology of Uitenhage," in the "Eastern Province Monthly Magazine," 1857, says that at this locality the "claystone porphyry" is vesicular, evidently in reference to the amygdaloidal and vesicular basalt of the Zuurberg fissure.

THE WARM SPRINGS AT BALMORAL.

The water issues from several spots on a hill south of the Coega River on Balmoral at a temperature slightly higher than that of the air on a warm summer's day, so far as I know the temperature has not been accurately taken. The water has a distinct taste of iron, and the large amount of iron oxides deposited by it show that an iron compound, probably ferrous carbonate, is one of the chief constituents in solution.

From one of the springs water issues which has an astringent taste, like that of alum.

The deposit of black and brown earthy oxides of iron conceals the underlying rock, but there are cuttings through gravelly material that may perhaps belong to the Uitenhage series, and a large jointed slab of quartzite, through which one of the springs issues, might belong to the Table Mountain series.

[1] To Prof. Branco I am indebted for copies of his works on this subject, viz., "Schwabens 125 Vulkan-Embryonen." Stuttgart, 1894. "Die Gries-Breccien des Vorrieses als von Spalten unabhängige, früheste Stadien embryonaler Vulcanbildung" and "Zur Spaltungfrage der Vulcane." Sitzungsberichte der Königl. Preuss. Akad. der Wiss. XXXVI., 1903., p. 748 and p. 757. "Das Kryptovulcanische Becken von Steinheim," Abh. d. Königl. Preuss. Akad. d. Wiss. 1905.

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At one spot a shaft was sunk 40 feet into the ferruginous deposit in the hope of finding coal. The bottom of the deposit was not reached.

At the spring which issues from the joints in the quartzite slab a yellow mineral with metallic lustre occurs in the sand through which water bubbles, and the same mineral is found cementing together the sand in places at the bottom and sides of the cutting near the eye of the spring. The mineral has a pale yellow colour, and is occasionally in the form of irregular four-sided pyramids, though generally no particular shape can be seen. On exposure to the air it becomes dull, in the manner of marcasite.

Mr. J. G. Rose, of the Government Analytical Laboratory, separated the yellow mineral from the sand and analysed it, with the following results:—

Iron	36·4
Sulphur	32·4
Sulphuric oxide...	8·2
Silica and gangen	8·5
Moisture	7·1
Alkalis as Na_2O	3·6
Organic matter (by difference)...	3·8
	100·0

Mr. Rose says: "'Arsenic and antimony are present only in very faint traces (less than .001%), as are lime, magnesium, and chlorine. The chief constituent appears to be iron pyrites ($Fe S_2$), which forms about two-thirds of the weight of the substance. Some of the iron (3-4%) is in the ferrous state, apparently as ferrous sulphate ($Fe SO_4$), and some as ferric oxide, while the alkalies are probably in combination as sulphates."

Marine Beds of Tertiary or Recent Age.

In the Addo Hills, Grass Ridge, and the flat ground between Zwartkops and Coega Rivers, there are conglomerates and shelly limestones lying unconformably on the Uitenhage series.

On A. G. Bain's map,[1] published in 1856, these rocks are indicated and called "Tertiary," but no distinct evidence has ever been obtained to prove that they contain fossils of extinct species. Their occurrence at various elevations from a few feet (on the shores of Algoa Bay) up to some 1,300 feet (Addo Heights) make it probable that they include deposits representing a very considerable period.

[1] Trans. Geol. Soc. Lond., Vol. VII., 1856.

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The lowest lying of the marine beds examined during the present survey are those on the left side of Sunday's River, near Mackay Bridge. They lie about 80 feet above the sea, and they make a conspicuous feature in the hillside, because they are much harder than the underlying Uitenhage beds. At this place there are about 30 feet of these beds exposed. The greater part of the beds is made of a hard shelly limestone, from which the shells themselves have mostly been removed by solution. It is very difficult to obtain good specimens of these shells for determination. Pebbles are frequently abundant in these rocks, and parts of them are evidently beach deposits.

Shelly limestones like those along Sunday's River occur at many places on the Addo Hills, where wells have been sunk through them, and they are quarried for building stone near Sand Flats. Parts of the limestone south of Sand Flats, and on the hills near De Bruyn's Kraal, to the east, are very hard rocks, made up of broken shells, sand grains, and a few whole shells, but no collection could be made from them, because the shells would not break out, and there was no time to spend in chipping them out of the solid rock.

Though no definite evidence of the Tertiary age of any of these high-level limestones is yet known, it is by no means unlikely that such evidence will be forthcoming.

The Gravels.

Along the Sunday's and Coega Rivers there are frequently to be found patches of gravel at various heights above the alluvial flats near the present beds. These gravels are at once distinguished from the beach deposits by having their pebbles more closely packed, by the presence of various land and fresh water snails in place of the marine shells, which are represented by a few rolled fragments, and by the absence of a calcareous cement. Most of the pebbles were certainly got from the beach deposits upon which the higher gravels encroach.

APPENDIX.

Occurrence of the Wood Beds on Loerie and Gamtoos Rivers.

During the past year prospecting work has been done on the lignite in the Wood beds in the south-western corner of Uitenhage. Three drives have been made, two on the right bank of the Loerie River, about two and four miles respectively above its confluence with the Gamtoos, and the third is on the left bank of Gamtoos River, about three-quarters of a mile above the Humansdorp-road bridge.

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The upper drive on Loerie River has exposed sandstones, sandy clays, and conglomerates dipping 20° to N. 20° E. They are irregularly-bedded rocks, and thin layers of pebbles are found in the clays. A thick bed of conglomerate at the top of the drive, and exposed in the bank above it, is about three feet thick, and has an irregular floor; hollows in the underlying clay are filled with yellow, sandy conglomerate. The pebbles are of quartzite chiefly, but quartz schist, vein quartz, and slate are also found in the conglomerates.

The sandstones and clays have irregularly-shaped lumps of pyrites in them, evidently formed in the positions they now occupy. Lignite occurs in thin lenticular layers; the thickest exposed at the time of my visit measured two inches, and tapered out to nothing in a distance of eighteen inches. Thicker layers have, however, been found, but they also thin out rapidly. In many pieces of lignite the original structure of the wood can be seen as faint, originally concentric rings, now flattened out into ellipses. Some lignite occurs in fibrous streaks, branching in various directions through the clays; these are evidently roots, but no stems were found in connection with them.

In addition to the lignite, a brown or yellow semi-transparent inflammable resinous substance occurs in these beds. It is found in three forms: (1) Mixed with the lignite in lenticles; (2) as independent lenticles up to quarter of an inch in thickness; and (3) as small pebble-like lumps, apparently water-worn.

An analysis of this resinous mineral, by Mr. J. G. Rose, of the Government Analytical Laboratory, gave:—

Organic and volatile matter	50.97%.
Ash	49.03%.

The ash consists of silica, oxides of iron, and alumina and a small amount of alkalies; it was probably sandy matter mixed up with the resin.

This semi-transparent stuff is certainly a fossil resin, and the occurrence of such substances does not seem to have been recorded previously from any rocks in Cape Colony. It occurs also in the core from a bore-hole put down in the Uitenhage beds by the Railway Department at Glenconnor.

The lower drive on Loerie River is in very similar beds to those described above, and similar lignite is got from them.

The opening on the Gamtoos River bank is at the foot of a slope on which lenticular layers of conglomerate and sandy clays crop out. Grey clays and shales are exposed in the drive, and

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these contain more or less imperfect remains of plants. The recognisable plants are:—

Sphenopteris fittoni (Seward).
Onychiopsis mantelli (Brongn).
Zamites recta? (Tate).
Taxites?

The three first-named plants occur also in the Wood beds near Dunbrody, on Sunday's River, and *Taxites* is found at Herbertsdale. Lignite similar to that found on the Loerie River is interbedded with the clays and shales at the Gamtoos drive.

The lignite from this neighbourhood is so like that from the Sunday's River valley, of which an analysis is given on another page, that there was no need to have another analysis made, especially as there is no probability of its ever having an economic value.

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GEOLOGICAL SURVEY

OF THE

COASTAL PLATEAU IN THE DIVISIONS OF GEORGE, KNYSNA, UNIONDALE, AND HUMANSDORP.

BY

ERNEST H. L. SCHWARZ.

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GEOLOGICAL SURVEY OF THE COASTAL PLATEAU
IN THE DIVISIONS OF
GEORGE, KNYSNA, UNIONDALE, AND HUMANSDORP.

E. H. L. SCHWARZ.

INTRODUCTION.

The present report deals with the coast belt lying to the south of the Outeniqua and Long Kloof Mountains. In 1898 Messrs. Rogers and Schwarz published an account of the district to the west of George. In 1899 the writer described the Knysna Division, in so far as it was traversed in looking for outcrops of Enon conglomerate containing fossils, the nature of which rock being at that time not properly understood.[2] In 1903 the writer described the Uniondale Division,[3] and last year the Long Kloof,[4] to the north of the district now under discussion.

The area consists of a background of mountains, rising to a maximum of 5,497 feet,[5] and a comparatively narrow ledge forming a coastal plateau, shelving slightly towards the sea and elevated some 700 feet above sea-level. The plateau is cut off on the south very abruptly, with precipitous cliffs that can only be scaled at a few points, and there is scarcely any beach at the base. The rivers have cut deep gorges in this plateau, and for the most part are useless for irrigation purposes, from their depth below the general surface; where, however, the rocks traversed by the streams are soft, either consisting of Bokkeveld slates or Enon conglomerate, there are wider valleys and fertile tracts of alluvium. At one part an immense bank of sand-dunes has been added to the land in front of the cliffs, and between there is a low-lying tract of country, containing the famous George and Knsyna Lakes.

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[1] Report on the Southern Districts between the Breede River and George, Ann. Rept. Geol. Comm. 1898, Cape Town, 1900, pp. 37-54.

[2] Knysna, between the Gouwkamma and the Blue Krantz Rivers, Ann. Rept. 1899, Cape Town, 1900, pp. 51-64.

[3] Geological Survey of Prince Albert, Willowmore and Uniondale, Ann. Rept. 1903, Cape Town, 1904, pp. 72-137.

[4] Geological Survey of the Long Kloof, Ann. Rept. 1904, Cape Town, 1905, pp. 47-69.

[5] Sir David Gill, Geodetic Survey of S. Africa, Vol. II., Cape Town, 1901, p. 181.

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Among the rock formations, we have the end of the George boss of granite, and another mass, in outcrop showing as a boss, but probably only an immense horizontal offshoot from the great triangular basement of granite that underlies the extreme south-western portion of the Colony. Round the granite outcrops there are slates, phyllites, quartzites, carbonaceous shales, and peculiar white rocks, containing felspar and garnets; these are pre-Cape rocks, formerly called Malmesbury beds, but since the 1898 Report was written, so much new light has been thrown on these old sedimentary rocks that we now hesitate to correlate any isolated outcrop with the type occurrence in the neighbourhood of the Cape Peninsula; these old rocks are injected with granite veins and dykes of basic composition, now reduced to the condition of hornblende schists.

Stratigraphically, above these last, comes the Table Mountain sandstone, forming the whole of the mountains and by far the larger part of the plateau, especially to the east.

The Bokkeveld series exists by favour of the great folds that have let down small portions of these beds in among the harder rocks of the Table Mountain series, and the enormous denudation that has swept vast quantities of material into the sea, has left these sunken portions as small inliers among the older series.

A more recent folding has let down a softer formation in among both the Table Mountain and Bokkeveld series; this is the Uitenhage series, which is here represented by banks of conglomerate, sand, and clay, which were formerly called Enon conglomerate; now, however, when we know that the true Enon conglomerate forms a basement to a large thickness of beds, the top of which only contains marine fossils, and we find the same marine fossils in the conglomerate in Knysna, we are not strictly correct in calling the Knysna rock "Enon conglomerate," though the great similarity in texture and composition would render the use of the term very convenient.

The sand is massed up in great dunes, reaching a maximum height of 912 feet at Belvidere, but ordinarily not more than 500 feet high; whether the Belvidere hills stand upon a basement of older rocks, themselves elevated above sea-level, as is most probable, or whether the sand commences right away from sea-level, cannot be accurately made out, owing to the whole country being covered, but we notice that the base of the dunes west of Knysna rest directly upon the coastal plateau, and that eastwards of the port the level becomes lower and lower, and west of the boundary, between the George and Knysna Divisions, the sand which has been consolidated into limestone, passes beneath the waters of the ocean.

In the larger estuaries of the rivers, such as those of the Knsyna and Bitou Rivers, there is a deep accumulation of greenish sand, and sand containing sub-fossil shells of species

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that are not common now on the shores of the Colony, though they are found in abundance on the Natal coast. This estuarine deposit is many scores of feet deep, and points to a period when the land was very much higher than it is at present, for otherwise we cannot account for the valleys having been so deeply eroded.

The soil throughout the district, except on the alluvial flats and on the narrow strips of Bokkeveld beds, is sour, that is, has an acid reaction, due to the accumulation of organic acids elaborated by the roots of the plants. Under the soil there is a sub-soil composed of rock fragments, coated with iron oxide, or simply granular masses of sand cemented with iron oxide; this forms hard banks of ironstone when exposed on the surface, and is only found under sour soil. The acidity of the soil is found equally on granite and Table Mountain sandstone, and is due to want of drainage, rather than to the nature of the rock sub-stratum.

THE GRANITE AND PRE-CAPE ROCKS.

The granite mass of George is in many ways different from the granite found to the west, in Robertson, Paarl, Malmesbury, and adjoining districts, for it is principally a white mica granite, whereas the western rock is usually a biotite granite. Exceptions to this rule naturally occur, but, on the whole, the general statement is correct. In another way, the granite of George is different from the western rock, in regard to its internal nature; usually such granite masses are solid bosses, that have segregation veins within their substance and dykes coming off from the parent mass, but otherwise the cores are in the state in which they first consolidated, and show no evidence of having been affected by the enormous stresses that acted around them, and altered and crumpled the rocks which they have injected. At Robertson there is a great boss of unaltered granite, surrounded by a zone of gneiss, schist, and rock derived partly from granite veins and partly from the sedimentary series, the last showing how intense the crushing force must have been which could thus form a transfusion rock. The course of the great Worcester-Swellendam fault, at the base of the Langebergen, clearly enough demonstrates the same thing, for this fault, which comes from near Worcester, is deflected in a half-circle round the granite boss, and resumes its straight course on the other side; or, to put it another way, the mountain building forces, which caused the whole strip of country to the south of the fault to drop some 10,000 feet, has been insufficient to affect the granite. In the George granite, however, the mass of the rock has been shifted and crushed, while later injections have been thrust into the gaping crevices which formed during the action of the mountain building forces.

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Some fine examples of later injections are exhibited in the cuttings along the new George-Mossel Bay railway, those near the Malgaten River especially; here we have the rock riddled with large and small veins of granite, profusely scattered with tourmaline crystals. In a road-metal quarry some three and a half miles from George, towards Knsyna, there is shown a very large dyke of binary granite, with a mere trace of biotite and tourmaline, injecting a mass of gneiss, which here has weathered into a loose sand. Coming from the dyke, there are quartz veins, which show faulting. Still further along the road, before descending the hill to the Kat River, there is a big granite dyke, itself riddled with smaller dykes of fine-grained rock, and binary granite with tourmaline. The first kind of dyke cuts through the coarser rock in the usual way, but the tourmaline pegmatite follows joint planes in the rock, and is undoubtedly subsequent to the crushing which the parent rock underwent.

Down towards the Kat River, however, we enter a region of slates, heavily injected with granite dykes, which were not mapped in detail; all we can say is, that the main mass of the George granite has come to an end. The true relations of the igneous and sedimentary rocks about here must always remain indefinite; the country has been denuded and levelled to a plain some 700 feet above sea-level, and this has been cut into by a number of rivers, which have made winding gorges, with precipitous sides. It is only in these gorges that one obtains outcrops of rocks, all the surface of the high-level plain being covered with soil, and the sections exhibited in the gorges are so varying that any attempt to piece together the geology of the country from them ends in hopeless confusion.

On the north and east the granite of George is bounded by slates, normal, sheared, clay slates, with occasional rich development of mica; they are badly exposed, and the various kinds that one sees around Worcester, for instance, all merge here into a brown micaceous product resulting from weathering. To the east of the George granite there is a change, for there is a great development of andalusite, sometimes in perfectly formed crystals, at others in half-formed crystals, that are mere knots and lumps in the micaceous rock.

At one place on the way to Knysna, after passing the first bridge, namely, that over the Kat River, and about five miles from George Town, there is a very interesting outcrop of andalusite schist, which has often been referred to in descriptions of South African geology. In the sheared clay-slates there is a small dyke of muscovite granite, showing in the road-cutting an elliptical section; on the lower side there is a number of very small accessory dykes, not more than an inch or so in diameter. The major axis of the elipse and the direction of the dip of the clay-slates is about south-east, 45°. On the upper side there is a zone of clay-slates, sheared, and presenting no particular

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features of interest, but then suddenly, some five yards from the granite dyke, there is a magnificent section of andalusite schist, with big crystals, up to two inches in length, scattered all over the surface. There seems to be no alteration in the composition of the slate to account for the change, and one is led to conclude that the new mineral formation does not take place in the zone of greatest heating.

On the south, the George granite is intensely jointed, with a general dip of the joint planes to the south or a little to the east of south. A north and south jointing super-added, cuts the mass into immense blocks, which weather out in the stream beds. The lower course of the Malgaten River shows this very well, especially where the new railway bridge will be built. On the extreme south, the rock becomes a gneiss, and is cut off by very steep cliffs, which fall towards the sea, with an inclination of 60° and more.

Near the Gwaayang's River, along the railway-cutting, there is a thin strip of slate in the substance of the granite; it is only a few feet thick, and is in the condition of phyllite. Further towards the coast, there is a wider band, and right on the coast, at Herold's Bay, there is exposed a narrow fringe of slate, the gneiss having been worn from off it.

As we go eastwards, this extraordinary relation of the gneiss, slate, and granite becomes clearer The first thin bed of slate widens out into the general mass of slate east of the great granite boss, but the second contains many peculiar characteristics; and though it eventually merges into the general mass of slate, it is separated from it for a good distance by a zone thickly penetrated by granite veins.

On the seaward side, the granite turns into a gneiss, and overlies the slate, dipping seaward at from 45° to 60°. It continues eastwards as a narrow belt, forming the prominent headlands on the coast as far as the Kaaiman's River; thence it skirts the edge of the high-level plateau, which is from this point situated inland, owing to the accumulation of sand dunes in front of it. The strike of this belt, also, alters at this point, from N.E. to E.N.E., and there is a very great importance attached to this change in direction, which will be discussed later. Further east, it joins up with the Touw's River-Hooge Kraal mass of granite. I take this mass of gneiss to be a once vertical dyke of granite that joined the two large bosses, and that subsequently earth movements were started, which altered the rock into a gneiss, and caused it to assume an inclined position.

The gneiss grades off on the under side, that is, on the north, into peculiar felspathic white rocks, containing zoisite and colourless hornblende, as well as garnet, all three alteration products of the original granite. This zone of intense dynamo-metamorphism apparently occurred only on the north side of the dyke. There is very constantly on the under-side a dyke of

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what was probably once dolerite, but which now exists in the form of hornblende schist. After this come quartzitic rocks and then ordinary phyllites, intensely sheared and crumpled.

This succession can be followed very well at Victoria Bay and along the fine sections between Kaaiman's Gat and the Wilderness. The phyllites continue backwards from the gneiss for some distance, all dipping at an angle of 60° to the south-east or east-south-east, sometimes with incipient alteration showing as spots and knots on the rocks. Then come quartzites and carbonaceous slates. The latter contain a notable percentage of plumbago in a flocculent form. One sees these black slates at many points in the pre-Cape rocks, especially near limestones—for instance, in Dassies Hoek in Robertson and in the Cango District in Oudtshoorn. In George they are well exposed on the road going down to Victoria Bay, at the Schaapkop's River mouth, at Kaaiman's River, and on the road down to the Wilderness; they are also found north of the Hooge Kraal granite. I do not think that any commercial value attaches to the rock, owing to the small content of carbon, and the flocculent form in which it occurs, which would render concentration impossible.

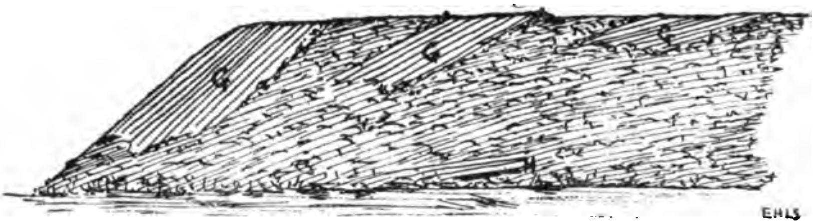

FIG. 1.—The mouth of the Touw's River, showing the beds of gneiss, G, repeated three times by faulting. At the water's edge there are white felspathic rocks, with hornblende schist, H.

At Schaapkop's River an excellent section is exposed in the river bed; the black rock is seen tonguing into white quartzites, and many granite veins traverse the whole series; lenticles of the black rock occur quite isolated from the main bulk.

The many small granite dykes that traverse the slates behind the great coastal one, are coarse-grained veins, which form an irregular zone of injections; they give rise to peculiar caves along the sides of the rivers, and are sometimes pressed out and sheared with the phyllites. The main mass of granite cannot be very deep below the slates between the two great bosses, the George Town one and the Touw's River-Hooge Kraal one, and it appears that these small dykes are offshoots into the slate that took advantage of any cracks that were formed after the original intrusion.

On the east bank of the Touw's River, the great coastal dyke is faulted (Fig. 1); that portion forming the edge of the cliff dips seaward at about 50°; behind it at the top there is a de-

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tached block dipping at about 35°; and behind this again another one dipping at 15°. The section is obscured on the lower portions by débris and forest, and it is at first puzzling to account for the granite capping to the cliff; the rock rises out of the bush and scrub in the form of immense boulders. At the water's edge there is a small exposure of sandstone grit weathering red, hornblende schist in thin layers and white felspathic quartzites, the whole of these stratified beds dipping at a low angle seawards.

The shallow waters of the Lange Vley wash the base of the cliff further to the east, and beyond, the whole face of the Touw's River-Hooge Kraal granite towards the Lakes consists of these sheared rocks, gneisses, and felspathic quartzites.

Following the Touw's River up from the mouth one loses all sight of the granite after the initial wall of the great dyke is passed, and the river is seen to be cut in a plateau made up of slates, phyllites, and gritty rocks. Near the main road, however, the western end of the Touw's River-Hooge Kraal mass is seen on the right bank of the river.

The slates between the two great granite bosses are intensely sheared for the most part, but along the Kaaiman's River there is a great mass of sandstones and quartzites, which are indistinguishable from the Table Mountain sandstone; these, being of great thickness and hardness, have not been so much affected by the crushing as the softer argillaceous beds; nevertheless, they have to a certain extent participated in it. Near Pacaltsdorp, to the south of the main granite, there are similar quartzitic rocks, but along the Touw's River to the east they have disappeared. I am inclined to think that these are merely sandy beds in the Pre-Cape series, for had they been really beds belonging to the Table Mountain sandstone, it is hard to explain how it is that they became involved in a crushing which must have occurred before the deposition of that series. The quartzitic beds grade into the slates down the road to Kaaiman's Gat, but much of the junction has been obscured by the earth movements.

Kaaiman's Gat is an immense hollow cut in the quartzitic beds; the mouth of the river is of a type frequently met with in the Eastern Province, where two main rivers unite to form one common entrance to the sea. On the east the Kaaiman's River with a large tributary, the Silver River, drains a large portion of the Outeniqua mountains; after leaving the Table Mountain sandstone it emerges on an area of slates and phyllites of no very great weather-resisting powers. On the west the Kat and the Zwart Rivers draining a smaller area, skirt the northern border of the George granite, but they fall into a region of granite dykes, which form impediments in their course. The western streams, then, from their lesser drainage area and the harder rocks they have to traverse, have been unable to cut into the

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high-level plateau to such an extent as the eastern streams, and whereas the latter have been able to cut a moderately graded river bed for themselves down to sea level, the former, when they come to the sea, have the bed of their united waters still some 100 feet above the sea level; they therefore pour over a krantz as a magnificent waterfall. The swirl of the waters has cut a round-barrel-shaped hollow with straight sides, and the impact of the falling mass has excavated the bottom of the hollow many fathoms below sea level. The sudden change of strike in the coastal granite dyke at the mouth of the Kaaiman's River has evidently been the cause of these rivers selecting this particular spot at which to eat their way seawards, for the bend was produced after consolidation of the dyke, and the motion must have crushed the compact rock. All these rivers, the Malgaten, Gwaayang's, Schaapkop's, Molen, and Kaaiman's, have their beds, as they enter the sea, quite normal, and they do not occupy channels that have been excavated many fathoms below sea level at an earlier period, as in the case of the Great Brak, Knysna, and Keurboom's Rivers.

On either side, at Mossel Bay and Knysna, there are extensive deposits of Enon gravel, and the absence of this formation over the area under discussion points to an up-lift after the deposition of these Lower Cretaceous beds; then there was a general levelling of the coastal plateau, cutting to a flat surface equally the Cretaceous and older rocks. The whole drainage of this part of the country was re-distributed when the plateau began to rise, and these rivers in George date from that time; the Plateau may have been cut as far back as late Tertiary times, but it is certainly of no greater geological age.

The Touw's River-Hooge Kraal granite mass is nearly hidden by deposits laid down on the coastal plateau, and where these are absent, by deep weathering. Nearly the whole area is covered with grass and soil, and in the kloofs by forest. There are good exposures, however, of the granite on the western bank of the Touw's River, along the southern border, in a gneissoid state, and down the Zwart River which forms the boundary of the George and Knysna Divisions. It appears to be generally a white mica granite, without the tourmaline veins which characterise the George mass. On the southern border it joins up with the crushed gneiss dyke, and on the north, also, along the Olyvenhout's River, there is exposed a similar zone of crushed gneissoid rocks, with shear planes dipping at a very low angle to the north. The nature of the rocks along the Olyvenhout's River reminded me very much of the sheared zone on the south of the granite boss at Robertson, where the Malmesbury slates, thickly injected with granite veins, have been caught between the resistant boss on the one hand and the great Worcester-Swellendam fault on the other. North of the crushed granite there are slates, but so badly ex-

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posed that no boundaries could be seen; the whole of the river valley is densely clothed with forest; at the upper sledge-path drift there are some black carbonaceous shales.

Down the road to the Geelhoutboom River there are white sandy beds, and near the Karaatera River undoubted Bokkeveld beds. It is impossible to trace the exact boundary of the Hooge Kraal granite on the eastern end. Between the main road and Zwart Vley there are slates which I believe are Pre-Cape; towards the vley the whole country is covered with sand, and the river valley is hidden with forest, which is almost impenetrable. A short exposure of rocks occurs on the last ravine leading into the Karaatera River from the east; they form a jagged ridge of Table Mountain sandstone and slates, which again I think are Pre-Cape, occurring as they do on the underside of the dip; the Table Mountain beds dip to the southwest.

On the Zwart River there is a better exposure of slates on the south side of the granite, and a road has been cut along the side of the ravine from the farmhouse on the level of the Zwart Vley to Hooge Kraal on the high-level plateau, and thus we are able to get a glimpse of the country rock from underneath its covering of sand and forest. The slates are gently folded, but intensely sheared, and consist of slates, phyllites, sandy slates, grits, and quartzites. Near the top there are rocks weathering white, and resembling the white felspathic rocks of Victoria Bay, together with phyllites and grits. In among these there are several fine-grained granite dykes, and finally a large dyke of hornblende-schist. From the road one looks down into a narrow V-shaped gorge, 500 feet deep, clothed on both sides with luxuriant forest; at one place there is a small waterfall, and the rock appears from a distance to be granite, but I was unable to make my way to the place, and could not determine whether it was part of the main granite mass or a vein like those along the road.

As far as we know, these patches of slate and granite are the last of the Pre-Cape rocks in the Colony in an easterly direction. Mr. Dunn marks Namaqualand Schists at Hankey, along the line of mountains which would bring them in the same set of folds which expose the Pre-Cape rocks of the Cango; so far this district has not been surveyed. As regards the granite, however, the Hooge Kraal mass is certainly the last, and it is not till one crosses over into Natal that one again finds this rock. Coincident with this termination of the granite, there is a marked change in strike in the mountain chains: hitherto, following them from the west, they have run fairly due east from Worcester, but hereabouts they bend round the end of the granite and assume a direction distinctly south of east. This fact is clearly brought out on all small scale maps of the Colony; along the sea-coast, the actual corner of the bend can be pointed out, for it occurs at the mouth of the Kaaiman's Gat River.

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In the general structure of the mountains, also, there is a great change that becomes apparent in this neighbourhood. At Montagu Pass the folding is still intense, and the separate limbs are closely pressed together as if huddled against an immovable block; north of the Touw's River-Hooge Kraal granite the folding is inconsiderable. In the Long Kloof, there is a sudden widening of the folds, and whereas from the west there are only southerly dips to be noticed, east of the termination of the granite there are northerly dips.

These considerations have led me to think that the Touw's River-Hooge Kraal granite mass has not acted as a buffer to the folding that broke against it, like the George mass, but that it has yielded and turned from an original north-easterly direction to a more directly easterly one—that is, through an angle of 15° to 20°. If my reasoning is correct, then we must regard this block, not as one anchored to the great basement of the earth's crust, but as an immense horizontal tongue or offshoot from the main granite masses that underlie the sedimentary beds in the south-west corner of South Africa.

The great shearing that has taken place in the George granite would, on the above theory, be the result of the lateral stress, not sufficient to shift the whole mass of the granite, but tearing through the more superficial portions and producing the cracks which are now filled with the tourmaline veins. The great coastal dyke was crushed at the same time, and the constituent minerals re-arranged, while the sedimentary rocks behind it were metamorphosed. What was in front of the dyke, that is to say, in the forward side of the movement, we cannot tell, as all has now been removed by the action of the waves, but in all probability there were Pre-Cape rocks, such as we find along the lower course of the Kaaiman's and Touw's Rivers; the shearing and crushing that they underwent, by imparting a fissile character to the rock, rendered them no doubt easily acted upon by weathering agencies, and facilitated their removal by the wash of the breakers. I think it improbable that the present coast line along this portion of the coast has been determined by folding or faulting; such movement found relief further out to sea, and is consequently out of the range of possible investigation.

The Table Mountain Sandstone and the Bokkeveld Beds.

These two series form by far the larger surface of the area under discussion.

North of George Town, the Outeniqua mountains rise to heights of about 4,000 feet; the range is not a sharp escarpment, but consists of a high backbone, with long lateral spurs, between which there are deep, wide kloofs. The boundary be-

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tween the Pre-Cape slates and the Table Mountain sandstone is covered with soil and often with forest. There is a variety of the sandstone, produced by the covering of damp soil, which is so loose and friable that it can be cut with a spade; it is not argillaceous, but looks so like decomposed Malmesbury slates that one cannot tell the difference till one crumbles the material between the fingers. The decomposed rock has many coloured bands, red, pink, and yellow, and sometimes brown iron oxide streaks. Occasionally one sees hard centres which have not yielded to the softening, and quartz veins that traverse the rock are naturally unaffected. This rock is frequently found in the forest near the junction of the Pre-Cape rocks, and helps to obscure the passage from one system to the other.

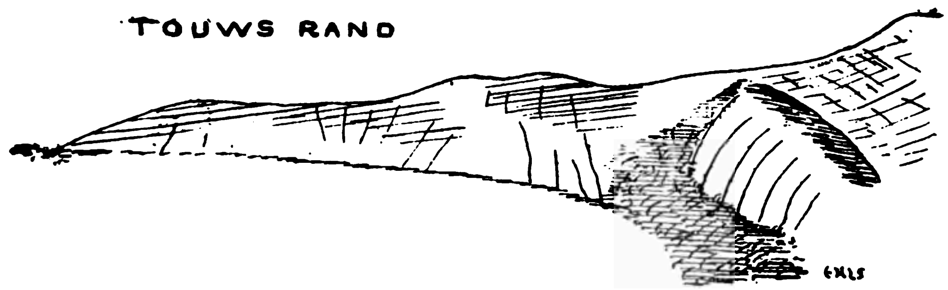

FIG. 2.—Touw's Rand, showing the projection of the Table Mountain sandstone to the south.

At Touw's River there is a portion of the sandstone jutting out southwards, called Touw's Rand; it is cut off on the east by an escarpment in which the strata are shown dipping south. Behind this projection there is a great wall of massive blocks of sandstone running eastwards along what is henceforward the general boundary of the Table Mountain sandstone (Fig. 2). Touw's Rand has been thrust forward between the two great granite masses, and apparently indicates the more pliant nature of the Pre-Cape slates as compared with the granite.

Touw's River, Deep River, and Zwart River have excavated very large, wide basins for themselves in the mountains, and there is a very remarkable difference in these to similar ones further west: in the latter one finds the rocks steeply and intensely folded, but here, at Berg Plaats, for instance, the beds are quite unaltered by secondary folding, and the strata sweep down from the crest of the range in one vast inclined plane.

At Millwood one enters again the folded region in the mountains; the beds are steeply folded with a strike that turns round to the south-east. I count five main synclines running in this direction, south of the mountains, in the coastal plateau between Knysna and Storm's River, and I think it will be best to describe

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each in turn, beginning from the westernmost. None of the synclines is a continuous, even trough, but there are broad cross folds, which raise the level of the fold, and where there are Bokkeveld beds included, these are repeatedly cut out on the surface by having been raised above the plateau level.

The first syncline includes the Rooi Kraal area of Bokkeveld beds, and probably also a succession of deep hollows in the Table Mountain sandstone, which are now occupied by deposits of Uitenhage age, which are of a later date. The true line of the syncline would follow up the Groot Kop's River, and come out at the south end of Plettenberg's Bay; the Uitenhage outcrops lie outside the axis of this fold, and will be described separately. The Rooi Kraal Bokkeveld beds occupy an area approximately four miles by six. On the main road they come in with great suddenness after the granite which one sees coming from George, and there is hardly space for the full thickness of the Table Mountain sandstone to exist between the outcrops of the two rocks, a fact which suggests hidden faults. The sandstone shows some remarkable parallel faults in the short cutting near the Karaatera River bridge, and slips of the inclined strata have been dropped twelve to twenty feet between vertical walls. The Table Mountain sandstone in most places ends abruptly on top, and one can see the exact junction between it and the overlying Bokkeveld beds, but at the Karaatera, and we shall again see, in the Knysna mountains, there are soft argillaceous-looking white beds, which are really decomposed sandstone, and render the junction very indistinct: we have already recorded the same fact from the bottom of the series where it overlies the Pre-Cape rocks in George, and the occurrence, therefore, seems to be due to infiltration of water rather than to original lithological difference.

At Rooi Kraal, or the post office, Barrington, the junction is not seen; the farm lies in the same level flat as occurs in the granite area on the west. Outcrops are confined to occasional quartz-reefs that project above the sandy soil, but these tell us nothing, as they occur equally in the sandstone and slate formations. If one follows the Little Homtini down to where it runs into the main Homtini, one can see fine exposures of slate-rock all the way; in the less precipitous side kloofs the slates weather in a manner very similar to the Caledon and Swellendam Bokkeveld beds, that is to say, they break down into greasy yellow clay with red stains. No fossils could be found here, except very small red patches, filled sometimes with a silky white fibrous mineral. Further down, the river runs in a precipitous gorge, with slate banks rising 300 to 400 feet: these show numberless large white quartz veins, which at Eland's Kraal are being prospected for copper. In an appendix there will be found a short account of the ore deposits in the Bokkeveld beds. As a rule, the beds dip 30° W. of S. at about 30°; the quartz

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reefs follow the strike of the beds, but dip about 45° in the same direction as the strata. Along the Homtini River the banks are very precipitous, and the lower slopes are densely clothed with forest; near the junction of the Little Homtini the sandstone again comes in, but I was unable to make my way to the actual spot. A little further down, below the embouchement of the Huis River, there is a wide bed of banket or conglomerate, which corresponds to a similar one found above the slate outcrop in the same river, and is evidently joined to it by a connecting sheet of banket passing under the slates. These bankets are very similar in appearance to the Rand auriferous conglomerate, only there is slate in the matrix; the gold content is very low, never, as far as prospected, ranging above 2 dwt., but then very little work has been done on these Knysna conglomerates.

The limits of the Rooi Kraal Bokkeveld area can be fixed within fairly narrow limits, but no boundaries can actually be traced, owing to the high-level plateau, which has been cut in them, being covered with soil; on Eland's Kraal to the south-west of the area there are large accumulations of blown sand.

Leaving aside for the present the hollows filled with Uitenhage beds, the rest of this first syncline is shown only in Table Mountain sandstone: the rock crops up out of the sand at Walker Point with a very irregular dip, sometimes to the south-west, sometimes due west. Following up the Homtini River, or, as it is called in its lower course, the Gouwkamma, from the mouth, there is deep sand till one comes to the drift, where some enigmatical gritty slates occur, unlike any of the formations in the neighbourhood; they are exposed in the road cutting near the river on the Knysna side, but one loses all sight of solid rock in a very short distance. Following up the river nothing is seen but an occasional krantz of sandstone projecting through the forest, until one comes to an immense chasm on the right bank. The river occupying this has apparently no name, but it runs into the Homtini just below Quarrywood. On the south bank there is an actual precipice of some 500 feet, but on the north bank the slope is about 45°, and a pathway goes through the forest up to Quarrywood.

Knysna village lies partly on Table Mountain sandstone and partly on Enon conglomerate. At the east end there is a large quarry, from which the building material for the fort was obtained, and in it there is a fine section of an anticline, each bed forming a semi-circular arch; it is a very good example of how hard quartzite like this can accommodate itself to strains, for naturally in the process of bending each stratum was stretched on the outer surface and compressed on the inner, yet there is no sign of cracking or crushing in the rock, nor are the beds separated by spaces. This fold is connected with the fault that lets down the Uitenhage beds to the east, and is, therefore, probably

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of a more recent date than the rock folds which we are describing.

Knysna Heads are cut in Table Mountain sandstone. The high-level plateau about Knysna village has been cut in Uitenhage beds, and these, from their easy disintegrating, have produced a wide hollow; along the sea, however, there is a ridge of sandstone at the normal height of the plateau, and the river cutting through this barrier has formed the picturesque heads.

The traces of the intense post-Uitenhage movements are visible in the sandstone in the extraordinary caves and natural arches that abound here. On the western head there is a very fine natural arch, over which a footway is carried, and on the eastern there are three immense caves facing the river (Fig. 3).

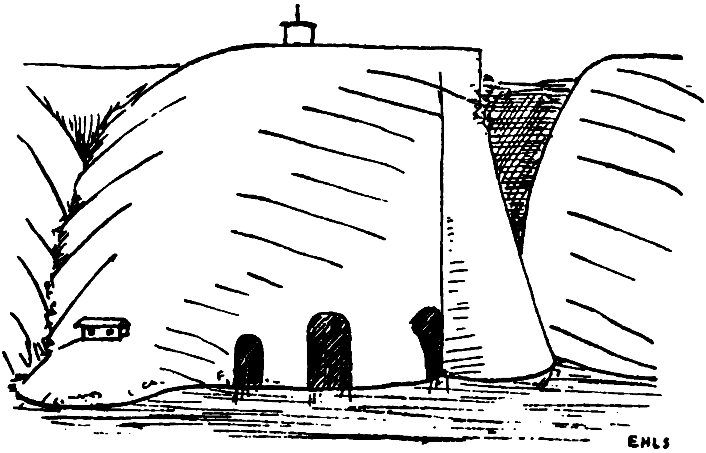

FIG. 3.—The Eastern Head, Knysna Harbour, showing the two chines formed along planes of crushing in the quartzite, and the three caves.

The eastern head also has two deep gullies in it which point to a crushing of the rock along planes which have been taken advantage of by flood water rushing down the hill side.

There is a small bay, called Barnard's Bay (Fig. 4), in the western head, and at sea level there are some rocks which look like coarse conglomerates: on closer inspection, however, the brown quartzite is seen to be actually a crush-breccia, and the rounding of some of the included fragments must have taken place *in situ* by the movement of the broken pieces over each other. Had these "autoclastic" rocks not been already described in Canada,[1] Lake Superior[2] and in the Isle of Man,[3]

[1] H. L. Smyth, Am. Journ. Sci., 3rd Ser., Vol. XLII, p. 331.

[2] Van Hise, Principles of N. American Pre-Cambrian Geology, 16th Ann. Rept. U. S. Geol. Survey, Washington, 1896, p. 679.

[3] Lamplugh and W. W. Watts, Crush Conglomerates in the Isle of Man, Q. J. G. S., LI, 1895, pp. 563-597. Lamplugh, Geology of the Isle of Man, Mem. Geol. Survey, London, 1903, p. 55.

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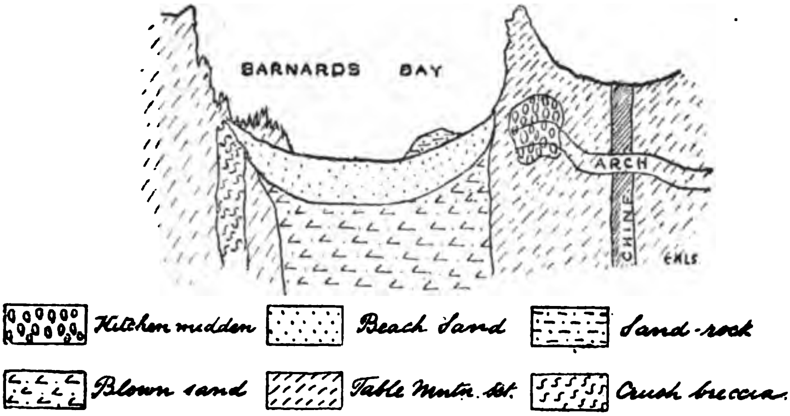

FIG. 4.—Barnard's Bay, Knysna Harbour, showing the position of the crush-breccia and the natural arch.

there would have been the material in these rocks in the western head of Knysna Harbour for establishing the fact that fragments can be broken from within a mass of rock and assume *in situ* all the appearance of water-worn boulders.

FIG. 5.—Arch and cave along the Knysna Coast, near Seal Point. Height of cliffs, 600 feet.

Further east along the coast there are several natural arches still standing boldly out from the cliff edge (Fig. 5), but a great many more have fallen, and the whole coast along here is studded with jagged rocks, among which the breakers are always

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surging. At the mouth of Knysna River these isolated rocks extend some distance out to sea, and make the entrance to the harbour exceedingly dangerous.

The old jetty at Knysna is made of slate, and until I heard the history of this I was very much puzzled to account for it, for I could find no quarry from which it could have been obtained. Ottrelite schist is said to occur somewhere to the east of Knysna, but I could not find the place; possibly there may be some down the Noetzee River. The Knysna jetty, however, was built of Malmesbury slate, carried in ballast from Cape Town. On the extreme end I also found granite, gneiss, vesicular lavas, and olivine basalts, together with white quartzite; this is also evidently ballast thrown out, but I could not hear anything about it; on the new jetty, however, there are curious granite and gneiss rocks, which I learnt definitely came in ballast in the S.S. Ingerid from Europe. Similar rocks are found strewn on the salt meadows on the western side of the harbour.

The second syncline starts somewhere to the west of Millwood, and after becoming unrecognisable for a considerable distance in the mountains, it can be again noticed along the Bitou River, though the valley in which this river runs is now for the most part occupied by Uitenhage beds, and the basin widened by movements much later than those which produced the original trough.

The main interest of this fold centres in the gold reefs which traverse the rocks in the Millwood area; in the appendix to this report will be found an account of them, with what appears to be the most rational view as to their gold content. The reefs run with the strike of the rocks, east-south-east, with a dip usually greater than that of the sandstones, and are similar in this respect to those along the Little Homtini River, where they occur in slate rock. In the sandstone, however, they have a more irregular course than in the slate, and tend to thin and widen out, and break up into stringers.

This fold is lost in the mountainous country to the east of Millwood. Near Plettenberg's Bay the edge of the coastal plateau is made of slates belonging to the Bokkeveld series, and these were probably in their present position before the Enon conglomerate was let down, and thus belong to the original fold. On the south side of the Bitou River two patches of slate appear through the conglomerate, one at sea level near the mouth of the Keurboom's River, and one in the hill behind.

The third fold was referred to in the Report on Knysna, but its western end was not traced. It is a double fold, for there are two narrow bands of Bokkeveld slate running parallel. A very thin slip is noticed on the Kruis River, west of the main road from Knysna to Uniondale, but it is not till some way down towards Paarde Kop that the rock can be at all well seen. The slates form a shelf on the south bank of the river, the bed

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of which is cut deeply in Table Mountain sandstone; they cross the Keurboom's River above the terminal straight portion, and run out to sea near the Groot River mouth. At this last point there is a marked change of strike from east-south-east to more nearly east, and these slates are picked up again, forming a ledge below the precipices of Table Mountain sandstone for a considerable distance along the Humansdorp coast. They are last seen just east of Storm's River mouth. The sea face of the cliffs here is covered with bush and forest, and about half-way down, or at an elevation of some 300 feet above sea level, there is a break or ledge formed of hardened slate (Fig. 6); the rivers that come off the high-level plateau cut through the Table Mountain sandstone, forming narrow ravines, but they end in the forest on the ledge, and the water must percolate through the almost vertical strata, and thus find an outlet to the sea, for

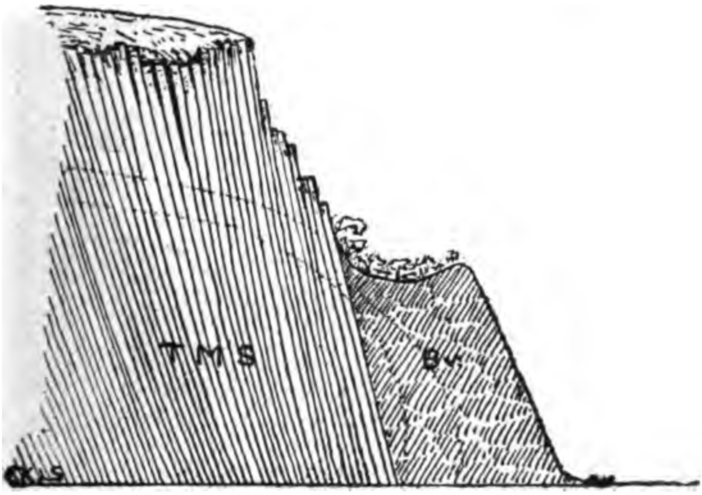

FIG. 6.—Section to the west of Storm's River mouth, showing the sea-cliff of Table Mountain sandstone (T.M.S) with the ledge formed by the Bokkeveld beds (Bv.).

there are no channels that run out of the slates along all this coast. According to fishermen, there is a submarine plateau that begins somewhere near Aasvogel Point, the edge of which is fairly well defined, and is well stocked with fish; off the mouth of the Humansdorp Groot River there is a sunken rock some two or three miles out to sea, which, though never at the lowest tides appearing above water, nevertheless is too near the surface for boats to pass over it, and in the calmest weather there are constantly breakers over it. I think it very probable that this plateau is formed by the spreading out of the Bokkeveld slates, as all along the coast the Table Mountain sandstone dips very steeply seawards, as it does at Storm's River mouth, for instance,

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where it clearly dips under the slates. The strike of the Table Mountain sandstone is continuous all along this coast, except for an occasional cross thrust, which brings the strike exactly east; this change of strike can be well seen at Seal Point and at the mouth of the Humansdorp Groot River (Fig. 7). Nothing very definite can be said about this supposed plateau till the shore is surveyed, but we have here all the factors that go towards forming a plain of marine denudation, namely, a large area of more or less soft rock exposed in a precipitous cliff to the full fury of the South Atlantic breakers. Portions will be constantly falling down, owing to the loosening of the rocks at

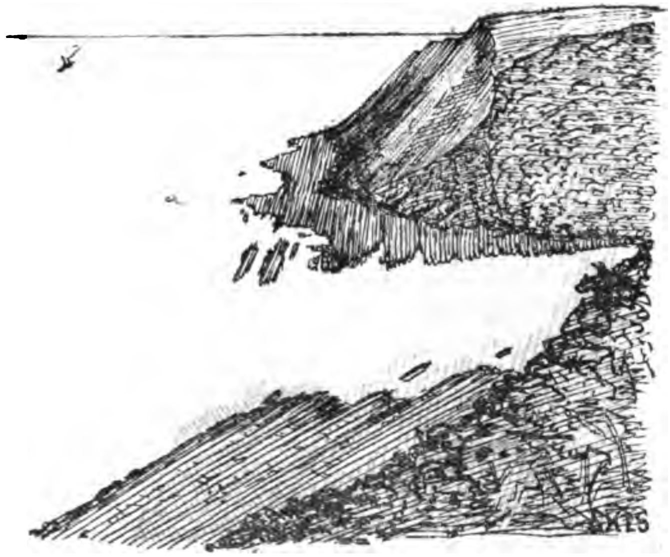

FIG. 7.—The mouth of the Groot River, Zitzikamma, showing the change in strike in the Table Mountain sandstone.

the bottom of the cliff by the pounding of the waves. These will be washed about in the surf, and will grind the sea-floor; not till this is reduced below the level of violent motion in the water will denudation cease. After all the slates have been removed from the face of cliff, the sandstone behind will naturally be attacked, as is the case east of Storm's River, but the rate of the reduction will be very much slower. It is, however, an indication of the newness of the high-level plateau, that the slate west of Storm's River has not yet been entirely swept away. Parallel with the western end of this outlier of Bokkeveld beds there is a strip of slates heading in the steep-ended kloof above which the road to De Vlugt runs; at the nek between this and the Kruis River valley there is a small shop and accommodation house, known as "Monk's." A small fold lets a

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strip of slate from the main mass in to the hill side on the south, but until the Keurboom's River is reached nothing definite can be seen in the valley, owing to the covering of sandy soil. The Keurboom's River runs down this slate outlier, and forms characteristic neks of red iron-stained rock; further down, the valley becomes very narrow, and finally the Bokkeveld beds get pinched out (Fig. 8).

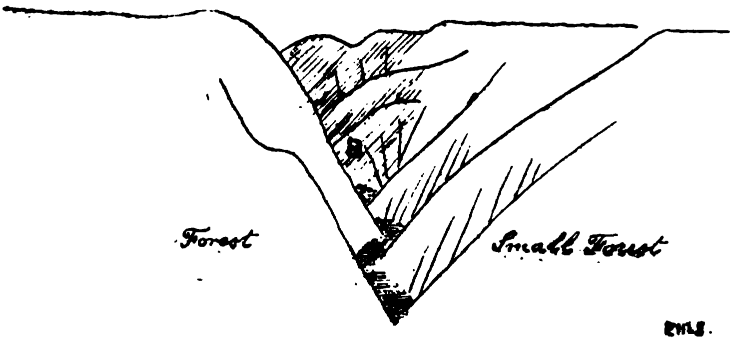

FIG. 8.—The valley of the Keurboom's River, showing the steeply dipping Table Mountain sandstone, and the end of the Bokkeveld beds (B) looking west from Paarde Vlakte.

The road from Monk's descends from the high nek to the Diep River; just before reaching the bottom the road crosses a thin band of slates, unmistakeably Bokkeveld, which, however, plunge into the steep hill side on the east of the river, and are enveloped in the Table Mountain sandstone. On ascending the hill on the north of the river, there is a great exposure of soft white, chalkey-looking sandstones, which I think belong to the Table Mountain series, but very near the actual top of the series. One is very much puzzled in a country like this as to where one is at any particular spot in regard to the rocks, as, for instance, a little further on, along the Assegaai River, there are again these soft sandstones, but here I regard them, having in view the general arrangement of the beds, as belonging to the shale band, near, but not actually at the top of the Table Mountain series; this bit of shale band is connected with the strip on Kykorie, which was referred to in last year's Report, p. 53, as being compressed in the bend which the strike of the rocks here assume.

Nothing very definite could be seen in the valley marked by the Deep River soft beds until, following the strike, one comes out on Jackal's Kraal. Here there is a wide flat formed of Bokkeveld slates, which cross the Palmiet River on to the Paarde Vlakte, at Jantjie's Stadt. The whole of the Paarde Vlakte is covered with sour grass, except where these slates come in, and their presence is very clearly marked by the sweet grass that grows upon them.

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The section (Fig. 9) along the Palmiet River finally sets at rest the puzzling phenomena of a strip of Bokkeveld beds, running with the strike of the rocks, but with the underlying Table Mountain sandstone dipping away from it on both sides, as if the slates belonged to an inlier of older rocks, instead of to an outlier of younger ones. At the Groot River, further to the east, this fold brings down the Bokkeveld slates again, and it was here, on a former occasion, that the same anomaly was noticed.[1] The Palmiet River section sets all doubts finally at

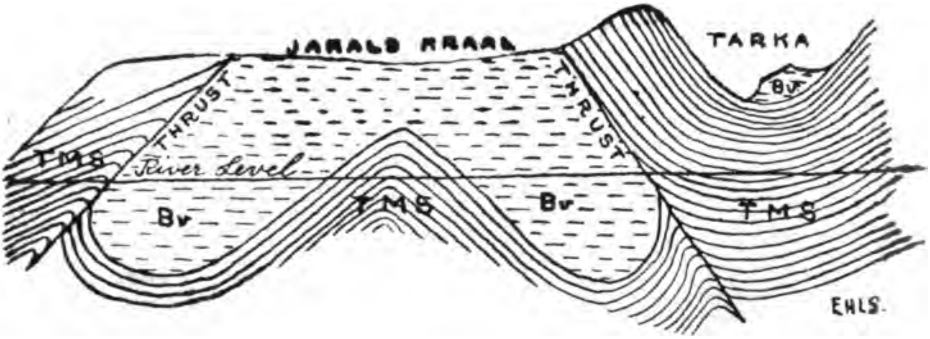

FIG. 9.—Section along the Palmiet River, showing Bokkeveld beds with Table Mountain sandstone dipping away from them on either side.

rest on this point, for just above the river level there is an anticline of Table Mountain sandstone that rises to the east, and finally widens out, so that the strata of which it is composed join up with the general sandstone beds of which Paarde Vlakte is made. The Table Mountain sandstone dipping away from the slates, likewise joins up with these strata as it is followed over the river to the east. The anamalous dip is explained by an anticline on either side of the slates originally inclined towards each other; these then gave way along their axes, and the outer limbs were thrust upwards over the inner ones, as represented in the diagrammatic figure. On the north side of the central anticline, between the sandstone and the slates, there is a reef of heavy, black, iron-cemented rock, which looks very much like an igneous dyke, but which is due to the deposition of iron from solution.

The last of the synclines met with in the district form the De Vlugt valley. It is occupied by Bokkeveld slates, which are cut to a level about 600 feet above that of the Keurboom's River. The river comes down the valley out of the Long Kloof, as described in last year's report (p. 54); about seven miles east of De Vlugt it suddenly abandons this valley, and cuts a tremendous poort through the ridge to the south, turns into the next

[1] Ann. Rept. Geol. Comm. 1899, Cape Town, 1900, p. 57. See also the same in Baviaan's Kloof, ib, 1903, Cape Town, 1904, p. 127.

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slate valley, along which it flows westwards again; cuts through another ridge of Table Mountain sandstone, and finally runs into another slate valley, down which it flows for a considerable distance. This remarkable winding can only have taken place provided that at one time the whole of the ridges and valleys that we now see were planed down to a common level; we can then imagine that where the river takes its first great bend, an accumulation of gravel rolled down from the mountains behind, blocked the course, and turned the river southwards, for there is nothing in the solid geology of the country to prevent the river from flowing down the slate valley right away to the Palmiet

FIG. 10.—View from Paarde Kop, overlooking the Keurboom's River Valley. In the distance are the Outeniqua Mountains; in front of these is ridge upon ridge of Table Mountain sandstone, sometimes separated by a valley filled with Bokkeveld beds, but each is cut down to a general level, the remains of an old peneplain.

River. Beyond what is known as Dwaas Nek, or the bank of slates which divides the waters of the Keurboom's from that of the Palmiet River, there are extensive flats of sweet veld. Near the main channel of the latter river, the syncline comes abruptly to an end, the Table Mountain sandstone being turned up round the slate like the bows of a boat.

The sudden ending of these slate valleys on a definite line is due, I think, to a broad fold, that has buckled up the land about here in a north-easterly direction; the movement probably took place at the same time that the Uitenhage deposits were let down into their present positions, and was not part of the great mountain building folds; it was again long previous to the

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cutting of both the lower coastal plateau, of about 700 ft. elevation, and of the higher one, of about 1,500 ft., which is now represented by the crests of the ridges south of De Vlugt (Figs. 10 and 11.)

FIG. 11.—View from Paarde Kop (2,397 ft.) looking east, showing the break of the 1,500 ft. plateau into the 700 ft. coastal plain. In the distance there is (1) Krakeel River or Peak Formosa (5,497 ft.); (2) Witte Berg (3,500 ft.) just above Forest Halt; (3) Spitz Kop (2,500 ft.) and (4) Zoet Kraal (3,143 ft.).

At the extreme east end of the Knysna Division there is a narrow strip of slates along the main road, folded in with the sandstone, which has very high dips, and is actually vertical on the north side; on the south side, the sandstone dips south, or away from the slate; and from the nature of the fold, this particular strip of slates may belong to the Jantjies Stadt-Groot River fold. The slates are well exposed in the drift over the

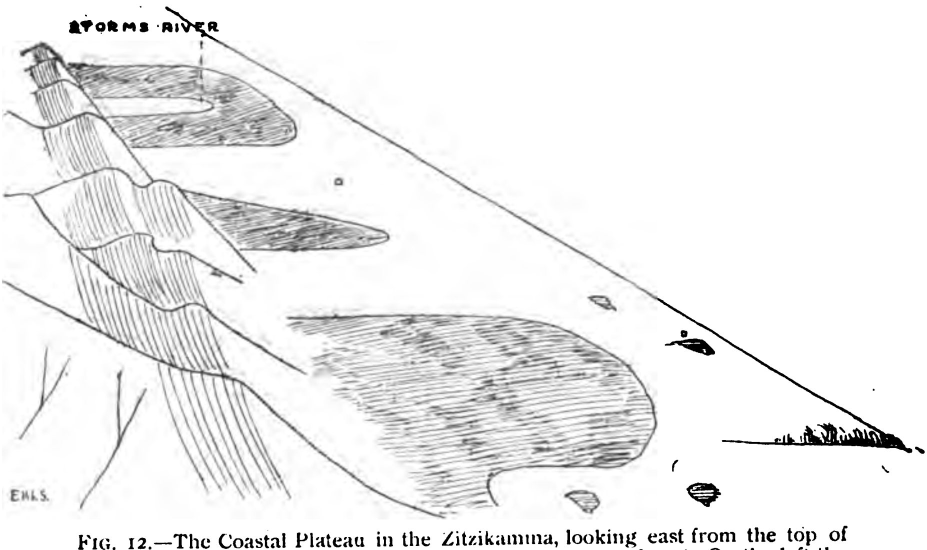

FIG. 12.—The Coastal Plateau in the Zitzikamma, looking east from the top of Coldstream Peak. The shaded portions represent forest. On the left the Table Mountain sandstone is seen, dipping steeply sea-wards.

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Blue Krantz River, and indeed the perpendicular walls of blue slate on the east bank give the river its name. The slates run a short way to the east, along the Hawthorn Kloof, but the valley is densely wooded; on gaining the level of the coastal plateau, there is nothing but sour veld to be seen, showing that the rocks beneath are Table Mountain sandstone.

The coast plain is here almost a desert, though there has recently been built a fine sawmill, to deal with the timber from the adjoining forests, and one house besides the forester's has been erected (Fig. 12). At Storm's River, however, there is a

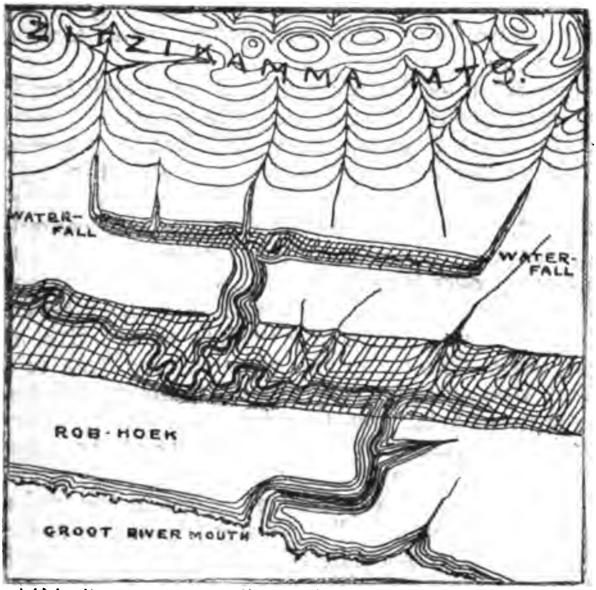

FIG. 13.—Sketch-map showing the two outliers of Bokkeveld beds, let in among the Table Mountain beds of the coastal plain. The area of the Bokkeveld beds is shown by the cross lines.

fairly wide strip of slate, the west end of which is hidden beneath deposits on the plateau, and by forest in the kloofs. In the Storm's River drift, however, good sections are to be seen. The slates can be picked up all along the same strike, namely, about 12° south of east, forming a gap, as it were, in the plateau, for the rocks being easily attacked by weathering agencies, have yielded readily, and the rivers that traverse the coast plateau have cut deep channels in this strip (Fig. 13). On the south, the plateau is of the normal height, and forms a ridge bordering the sea; it is very difficult of access, because of this slate valley on the north, with its deep forest-clad ravines, and the treacherous drifts across the rivers; while its length is inter-

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cepted repeatedly by precipitous walled ravines, through which the streams coming out of the depressed slate area reach the sea.

The most notable of these gorges is that of the Storm's River; on the coast, there is a little harbour, where boats and lighters shelter in a bay cut in the Bokkeveld slates, while a wire-rope connects the half-way ledge of slates with the sea level; small coasting steamers can anchor off the bar of the river, and receive their cargo from the lighters. Putting off from the harbour in a boat, one crosses the bar, and then enters this wonderful gorge; the actual height is, I think, rather over 600 ft. than under, and the walls are not only perpendicular, but actually overhang; at one place a tree flung across the ravine would form a bridge from side to side.

The eastern end of this strip of Bokkeveld beds lies further in the Humansdorp area than I was able to reach. North of it, near the Karedouw Pass into Long Kloof, there is a very narrow strip of slates, parallel with the larger one. (Fig. 13.) It is pinched out on either side, but on the east comes in again as a wider strip; the length of the first part is about five miles. The streams that come down from the Zitzikamma mountains run for a short way over the coastal plain, and then plunge into the deep gorge that the soft slates have allowed to be cut in the plateau, and many picturesque waterfalls occur; it is a remarkable sight, when riding over the grass-covered flats, to suddenly see a great waterfall plunging into what appears to be a great hole in the ground, for this transverse gorge is so narrow that one does not perceive it till one is actually at the edge. Some of the rivers, however, end in marshes at the edge of the ravine, and the water trickles away through joints in the rocks.

There is a magnificent valley, forming the head waters of the Palmiet River, which is locally referred to as Zoet Kraal, though the farm of that name only occupies part of the area. It is shut off from the Long Kloof on the one side, and from the coast plain on the other, by very steep mountains. The soil in the valley is entirely sour, but there are some softer beds in the centre, which appear from a distance to be slates, but they are merely soft beds in the sandstone; probably the Bokkeveld beds were represented, but they have now been removed. The valley is a syncline, and on the south side there is a magnificent anticline, shown boldly in the side kloofs of the mountains; looking east from the high peak above Coldstream, one sees this fold running far into the distance, with serried rows of hogs' backs marking the southern limb. The Zoet Kraal syncline rises rapidly, and on the southern banks of Peak Formosa the strata, bent into a trough form, can be plainly seen; beyond, the syncline becomes lost, and the south limb of the anticline closes in with the north limb of the syncline, the two forming the Zitzikamma and Long Kloof Mountains respectively (Fig. 14).

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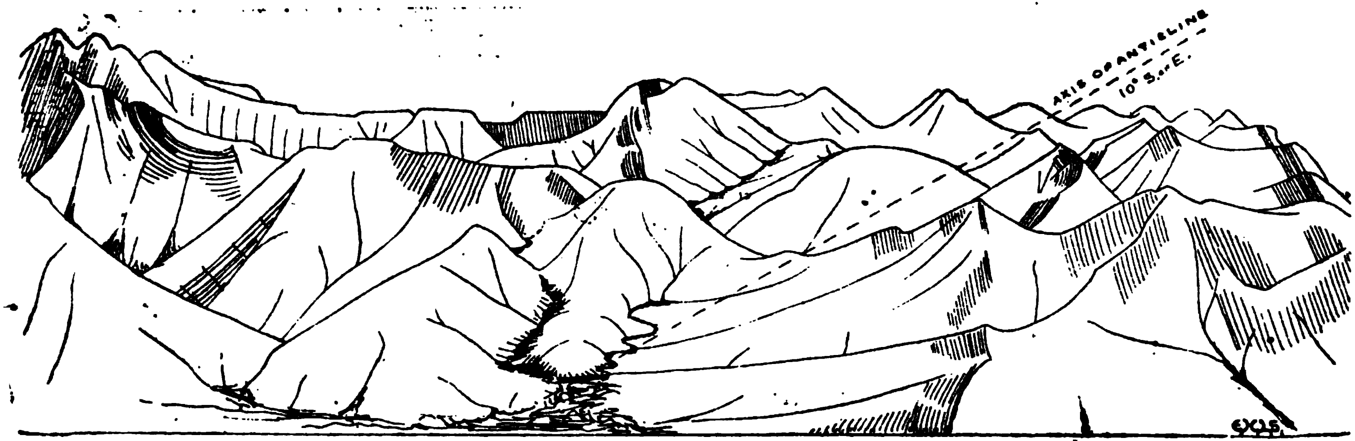

FIG. 14.—Folded Table Mountain sandstone scenery. View of the Outeniqua and Long Kloof Mountains, looking east from Coldstream Peak. The syncline that forms the valley of Zoet Kraal is seen rising on the left. The row of hog's backs, on the right, belong to the south limb of an anticline running 10° S. of E., that is, along the general strike of the beds on the coastal plateau about there.

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The range eventually dies out near the Humansdorp coast, becoming simpler and simpler in structure as one follows it eastwards, although there are disturbances across the strike of the rocks which tilt the mountain mass in the direction of its length; such an one can be seen at Karedouw Pass, where the mountains on the east have been lifted bodily above those on the west, and the road runs in the gap excavated in the crushed rock along the fault. The main road to Humansdorp from the Zitzikamma* passes round the end of the mountains, a point which is interesting in view of the immense length of the coastal mountain-chain; beginning in Bushmanland, we have traced it south, as the Bokkeveld Mountains and Cederbergen, to the great knot of mountains about Worcester, and thence eastwards, as the Langebergen, Outeniqua mountains, and the Zitzikamma mountains; on the north, where the mountains end, there is open country between the coast and the interior, but at the eastern termination, on rounding the point, one is faced with a vast complex of ranges, that bars the passage to the Karroo.

The Uitenhage Beds.

The Uitenhage deposits in the area with which we are dealing were referred to in the 1899 Report, and there are one or two points which I wish to add to the description published there.

In the first place, there are two areas where the Uitenhage beds are exposed, which were originally mapped as drift sand; the one is to the east of Knysna, and the other opposite the village, at a farm called Brentford.

The first one is completely covered with loose sand, and, indeed, is itself made up almost entirely of sands and clays; only on the south side can the conglomerate be seen dipping under the looser rocks on top. The new railway which is to run from Knsyna to the main forest exposes some fine sections of the loose sands and clays in the cuttings, and without these, it would have been impossible to discover these deposits. One deep section exposes an alternate series of reddish and brown sands and red and apple-green clays; further towards the conglomerate, some sandy white clays and even a pure white kaolinitic clay are seen. Between these two points the cuttings have exposed a grey shale, with indistinct plant remains; these were so strikingly like the Herbertsdale shales, containing *Cladophlebis browniana*, that I eagerly searched for the parent source of the rubbish on the embankment, but I was unable to find the rock *in situ*. The whole of the beds dip north-north-east at about an average dip of 15°; they abut on a hidden wall of Table Mountain sandstone, formed by a fault-face.

In the centre of these sandy Uitenhage beds there is a remarkable development of ironstone, formed by spring water

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[1] A Hottentot word probably meaning "rushing waters."

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carrying iron in solution, the mineral having been deposited, and now cements the sand grains into a hard rock. The springs at present issue behind the ironstone, but only in a small trickle; from the formation of the ground, the fault, and the loose sandy rocks filling in a deep basin, it is very probable that if these springs were opened up, a very large supply of water could be obtained; it is to springs in the same position that we look for our greatest supply, but the only one properly opened is the Uitenhage spring.

All over the high plateau about here, behind Concordia and on either side of the main road, near the Paling River, there are thick deposits of red sand, that merge towards the coast into the ordinary yellow drift sand; from the sections exposed in the new railway, I very much suspect that these red sands in part are Uitenhage beds, but it is impossible to say if they are in the position in which they were originally laid down, or whether they have been resorted by the wind.

The Brentford patch of Enon was passed by me again and again, but always mistaken for recent deposits, that is, sand-dune sand cemented with lime. Mr. J. Rex, however, showed me a Trigonia from the locality, and Mr. Rogers, on a recent visit, made an examination of the place, and proved the existence of fossiliferous marine Uitenhage beds.

There is a feature in the Enon conglomerate exhibited in the road cuttings down the Phantom Pass which calls for remark. The gravel beds are usually sorted out in regard to the size of the pebbles, large ones being collected in one zone, smaller ones in another, and sandy beds in a third, and so on; but in this particular place all varieties and sizes are tumbled together, in defiance of the laws of gravity. How came such a mixture of large and small boulders to be distributed through a sandy matrix? There is no possibility of invoking ice-action, but the mud-rushes in the Alps give some clue as to the origin of this. The rocks in high altitudes become disintegrated by frost and variations of temperature, and strew the hillside with debris; when a strong fall of rain occurs, this loose material absorbs the water until it can hold no more. At this point the whole mass begins to move—mud, sand, rocks, and water—and gathering impetus, flows down the hillside with a prodigious roar, the solid rocks grinding over one another, and the sand swishing over the surface of the ground[1]; observers have stated that a mud-rush of this kind resembles a lava-flow very closely.

When the Outeniqua mountains were first raised from the original plain of deposition in Jurassic times, they must have been enormously higher than they are to-day; it is true that their base was much lower, as we see from the old levels of denudation at their foot, but for all that, their mean height above

[1] P. Demontzey, Reboisement des Montagnes, Note A, Paris, 1882.

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sea-level must have been quite twice as great as now, that is to say, they rose to a maximum of over 10,000 ft. Such a height would give the excessive variations of temperature necessary to produce intense crumbling of the rocks exposed on the surface, and such a range bordering the sea would cause excessive rainfall. Both these conditions for the production of mud-rushes would, therefore, have been present, and the material when it came to rest would show the peculiar features which we see in the Enon conglomerate in the Phantom Pass.

NOTE.

Since the above was written, a most interesting mud-rush has occurred near Cape Town. The month of June set in very wet; there were recorded, from the 4th to 10th, the following readings:—.25, .50, 1.03, .87, .57, 1.35, 1.63; total, 6.20 inches for seven days. On the 11th it was still raining, and all the previous day the houses on the high-level road at Clifton were threatened by an inundation from the water flowing down the ravine behind them. There was a dam some distance behind the houses, strengthened by a row of full-grown pine trees, which turned the water into a furrow, and led it away from the little settlement. All night long men were stationed to see that the dam held, and everything seemed safe when morning broke. The workers then retired to the house of Mr. S. B. Mills to refresh themselves after their night's labour in the soaking rain. At ten o'clock on Sunday morning (the 11th), some people staying in the hotel below, came up to see how the people above were faring. As they came over the high-level road, they heard a dull rumbling, and shouted to the inmates of the houses to save themselves. The latter rushed out, and immediately afterwards an avalanche of water, mud, and trees swept down the ravine with the roar of a thunderclap. The liquid mass struck the row of pine-trees by the dam, and felled one of the central ones, and then swept over the little patch of garden ground below. The soil of this garden became liquid to a great part, and helped in the destruction; a big oak tree was carried away by the onset, and its roots plunged into the midst of Mr. Mills' house, carrying away the walls. The liquid mud then poured through the gap where once the building stood, over the high-level road, and down the steep slopes of the mountain side; some even reaching the low-level road by the Clifton Hotel.

The ravine begins some distance above the pipe-track, along which water is conveyed from the Kloof Nek to Sea Point. There was formerly a fairly straight main channel, with a side valley on the left; on the right bank, there was a steep cliff of soil and boulders, which has now been cut into, and a new lateral ravine has been formed. In the early part of the summer

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just past, the veld had been burned, and the woody *Protea* and other bushes had been reduced to blackened stems; the fresh grass had just begun to sprout at the time of the accident, and had not yet gained any considerable strength. The mud seems to have first begun to loosen in the side valley on the left and, collecting into a mass, to have flowed down with great velocity; the rush entered the main valley with a bang, for the steep wall on the right is splashed high up with the black mud, and then it must have torn down the ravine, sweeping everything before it. The soil on this slope is entirely composed of decomposed granite, and it is a curious fact that it is only the surface soil, blackened with the charcoal of the burnt bushes, that went to form the mud, a fact which perhaps explains the occurrence of granite debris along the slopes of Camp's Bay containing a small percentage of carbon, a deposit which it was attempted to exploit as a carbonaceous gravel. The only trace where the sub-soil has given way is on the steep wall above the junction of the top left-hand valley with the main one; here a portion of the debris slope has been torn away, leaving a clean yellow surface exposed. Large granite boulders, such as lie about the surface, were carried down by the rush, some coming to rest only at the very door of the Clifton Hotel, but the main bulk of the material was pure granite wash.

The occurrence was of very small dimensions, but the force of the rush was concentrated by the narrowness of the ravine; had there been a wider valley, no destruction would have occurred, as may be seen on the down-side of the high-level road, where the mud distributed itself harmlessly over the surface of the ground.

The occurrence is of special interest, as illustrating the nature of liquid mud rushes generally, be they formed by the accumulation of water in loose soil, or by the condensation of steam in volcanic scoriæ and ashes, and also the probable origin of the carbonaceous gravels of the Cape Peninsula; but it also explains the many valleys in and around the slopes of Table Mountain, which are filled to a great depth with loose sandy soil, evidently pure granite wish, even though the rock cropping out on the sides of the valley are such as could only afford a clayey soil, that is to say, belong to the clay-slates of the Malmesbury beds.

There are in the valley some boulders ten to twenty feet in diameter, composed of granite; these seem to menace the little settlement, one house of which is built actually under the shadow of one of these gigantic boulders. High up, where the main ravine forks, there is a large boulder, which has come down from above, but it appears shed from the parent rock; these other boulders resting on soil are fairly safe, as their immense

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weight would prevent the absorption of water by the soil under them. In the Enon conglomerate, which is in part derived from mud rushes of the kind referred to, there are never very large boulders like those of Clifton, and I think we can safely say that something more than soakage of water would be necessary to dislodge them.

THE SUPERFICIAL DEPOSITS.

Where the Kaaiman's River in George enters the sea, the coast changes; on the west, there are precipitous granite cliffs, rising 600 ft. directly from the sea, with but a narrow ledge of surf-cut beach, strewn with fallen boulders, and interrupted by pinacled, jagged crags, round which the waves are continually boiling; there are no sandy beaches along this shore, except in one or two small bays. East of the river's mouth, the same sea-cliffs are seen, but in front of them has been piled an immense accumulation of blown sand.

Blown sand on this shore is produced by the communition of shells, which are thrown up by the sea, washed about by the ebb and flow of the tide, till they are broken into tiny fragments, and thus become small enough to be caught up by the wind. Against a steep cliff, the sand does not accumulate in an inclined slope unless the prevailing winds strike inland at an acute angle; where they come full upon shore, there seems to be a back eddy, which causes the sand to build up a ridge with a valley between the sea cliff and itself. When it rains, this hollow becomes sodden with water, and vegetation springs up, and it seems that the back-eddy tends to push the crest of the ridge seawards, while the off-sea breeze piles up more sand; so it comes about that the ridge grows bigger and bigger, and advances outwards, while behind it is formed a marshy level tract, covered with bush and water-loving plants.

All stages in this process can be seen along the shore between Kaaiman's River mouth and Gericke Point; but in the aggregate, this action, having gone on for a very long time, has built up a mass of sand, 600 to 800 ft. high, along the shore, and left behind it a low tract, now occupied by a long string of Lakes, or Vleys, as they are known in South Africa.

First, there is a long narrow lagoon, forming the mouth of the Touw's River; connected with this there is the Long Lake, divided into two portions, with a picturesque island rising from the waters of the western half; then, entirely separated from the others, comes the Round Lake; then the Black Lake, a very extensive tract of shallow water, with long, winding branches;

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and finally, there is the Green Lake. All these lakes are more or less brak; they are shallow, depths of 15 to 20 feet being exceptional; while, as a rule, people can wade over the greater part of them. Each, however, has its own peculiar characteristics. The first portion of the Long Lake is bounded by high cliffs of sand, which almost shut it off from the other portion; the road, too, on the south side is carried through the water, there being no ledge beneath the cliffs; the island is steep, and has barely ground for a small house, which looks as if it is fastened to the south side. The eastern half of Long Lake lies in more open ground, and there are farm lands all round its margin. Round Lake lies also in among cultivated ground, and when the water is low, there are extensive tracts of salt meadow land, which carry large herds of cattle, horses, and ostriches. Black Lake is a dismal swamp, bordered with stretches of black, stinking mud on the south; but on the north side it is closed in with steep sand cliffs, covered in part with grass, and in part bare of all vegetation; the constant burning of the veld is tending to make the whole one barren, sandy waste. The great sea-cliffs of sand that have bordered the shore from the Kaaiman's River break away at Gericke Point, and the gap has been healed by the accumulation of sand of a more recent date; the blocking of the outlet of the Black Lake has caused the water channel to wind in among low sandy flats. On the east of the Lake, one enters a wilderness of sandhills, reaching at the Belvedere beacon a maximum elevation of 912 feet above sea-level, but the whole thickness from above sea-level to this point is probably in part made up of older rocks underlying the sand. Green Lake lies in among grass-covered hills, and on the borders there are small patches of forest; the south side is closed in with steep sandhills, rising 600 feet above the lake, and densely covered with forest, which every year is being encroached upon by veld fires. The margin of this lake is occupied by extensive marshes, on which grow two kinds of reeds, a dark, blue-green sedge and the lighter yellow-green matjes-hout, a sort of papyrus. After the depressing bareness of Black Lake, it is very astonishing to come upon this beautiful lake, with the green border and forest about it, though the Black Lake seen from the mountain tops behind, for instance, from Devil's Kop, looks as fair a sheet of water as one could imagine. The water of the lakes varies from almost sweet in the Round and Green Lakes to pure brine in Black Lake, though the quality is dependent on the amount of rain that has fallen in the district; after drought, all the lakes become brak.

The sand tails away on the upland plateau behind Black Lake and Green Lake, and brings a percentage of lime into the sour soil, rendering it sweet; hence these sandy patches are more thickly populated than the rest of the country. The lime is often dissolved out of the sand, and forms beds of pure white

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lime, which is quarried and burnt for building purposes. Otherwise, there is not the same formation of hard sand-rock as in the Bredasdorp downs, which was produced by the cementing of the grains by dissolved and redeposited lime. On the sea-cliffs between Kaaiman's River and Gericke Point, the sand looks like a rock, but is quite soft, although it has been cut away by the wind till the face of the cliff is quite perpendicular. The extraordinary false bedding in this sand is beautifully exposed in the cliffs, and endless examples can be photographed.

At Gericke Point a portion of the cliff has become separated, and stands out in a bold promontory, in which the false bedding is very well shown. The sand rock goes below sea-level here, and is cut into several plateaux; the higher, on which the headland stands, is not covered by water at ordinary tides; the water, collecting in the pools, evaporates, and leaves behind small deposits of salt, which is collected for the local fishery; the lower plateaux are always submerged, and the surf beats furiously against the edges of the intermediate ones, showing how greatly this soft sand-rock has become consolidated.

Similar ledges of sand rock follow the coast all along where the sand dunes are, not only here, but in Bredasdorp; west of the mouth of the Touw's River, they are never exposed, but their presence can be inferred from the numerous fragments cast up on the shore. The surface of the ledges is exceedingly rough, and is formed by hardening of the rock along cracks that traverse the rock in every direction, so that more or less hexagonal portions are enclosed by them; between these cracks the sand is softer and is easily removed, leaving the infilled cracks now standing up like little walls; and where two or more cracks meet, a little pinacle is formed. Sometimes the cracks are further apart, and leave large shallow pools, enclosed by low walls.

The question of these sunken areas of sand rock is one of great importance, for it implies a sinking of the ground, whereas we know that this sub-continent has been subjected to considerable elevation during comparatively recent times. I was at first puzzled to account for the hardening of the rocks, and thought that possibly this might have taken place in the ordinary loose sand that is washed up on the shore. The character of the rock, however, shows unmistakably that it is the wind-blown sand, consolidated before being sunk, and subsequently hardened by sea-water. That it can be hardened when below sea-level better than when exposed to the atmosphere seems paradoxical, but I think the process can be explained in the following manner. The sea-water contains carbonic gas, and under ordinary circumstances, retains this, and dissolves a little of the lime of the sea-shells. When the water

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is left at the ebb lying upon the sandy rock, it is heated by the sub-tropical sun, and the gas is driven off and the lime in solution is deposited over and in among the sand grains, thus binding them together.

I have read with attention the description of the stone reefs of Brazil, which occur on a coast bearing many striking resemblances to the one we are describing; these are beaches consolidated by the deposition of lime, and, according to Mr. Branner as not due to the sinking of the material. This author, however, admits that wind-bedded sand occurs below tide-level on Fernando de Noronha, an island not far from the Brazilian coast. At Port Elizabeth, on towards Cape Reciefe, there are typical stone reefs, that is to say, boulders and sand cemented together with lime, with oyster shells and other marine organisms imbedded in the matrix; and if the sand rock could have sunk on the George coast, it is probable that a like sinking occurred at Port Elizabeth, and in a similar manner, if sand-rock sank at Fernando de Noronha, it seems likely that the same fall may have taken place on the Brazilian coast. In Brazil, Branner records both depression and elevation, the latter later and of less extent than the former, whereas, on the George shore, the proportions are reversed. Among the evidences of depression are cited the rock-channels of Parahyba, now filled with mangrove swamps and mud, which have sunk at least 36 feet since the channels were cut, thus resembling the rock-channels of the Keurboom's River. Evidences of elevation occur in raised beaches in the Bay of Bahia, and at Ilheos, in the State of Bahia, there are as high as 24 feet.[1] In South Africa, there is the high-level plateau, 600-800 feet above sea-level; but besides this, in Bredasdorp, Mr. Rogers and myself found a well-marked beach, with large boulders, about 100 feet above sea-level, in the sand-dunes, above the roof of the cave at Cape Infanta.

This last fact proves beyond doubt that the sand-rock has at one time been sunk beneath the tide level to 100 feet, and the evidences for a large mass of it still beneath the water on the George coast are sufficiently satisfactory, so that the theory of the sand rock being ordinary beach-sand hardened *in situ* must be ruled out. We have then proof of a see-saw motion in the rising and falling of the land, the former largely prevailing.

Of the earlier temporary depressions, there are no traces left; but among the stages of elevation we have the 1,500 ft. plateau about De Vlugt; the 700 ft. plateau forming the present coast ledge; the 100 ft. beach at Bredasdorp; and the 10 ft. beach at Port Elizabeth. Below sea-level, we have the Keurboom's River rock-channel, 100 ft. below, and the plateau whose edge is

[1] J. C. Branner, Bull. Mus. Comp. Zoo. Cambridge, Mass., 1904.

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known as the Agulhas Bank, 500 ft. below tide-level. We can put the facts thus:—

There has been an elevation from some unknown depth to the edge of the Agulhas Bank	x
From the Agulhas Bank to Keurboom's River rock-channel	400 ft.
From this to Port Elizabeth raised beach	110 ft.
From this to Bredasdorp raised beach	90 ft.
From this to Uplands Plateau	600 ft.
From this to the De Vlugt Plateau	900 ft.
Total	x + 2,000 ft.

There has been a depression of the Bredasdorp raised beach to the Port Elizabeth raised beach	90 ft.
From this to the Keurboom's R. rock-channel ...	110 ft.
From this to the Agulhas Bank	400 ft.
From this to an unknown level	x
Total...	x + 600 ft.

As regards the 700 ft. Uplands coastal plateau, I have again seen reason to doubt the conclusion that Mr. Rogers and myself came to in reference to its being a peneplain or base-level of river erosion, and not a plain of marine denudation. The presence of Chara seeds in the capping quartzite in Komgha seemed to settle that the deposits found in the plateau were fresh water, but since then, Anderson has described a deposit containing Chara seeds on the shores of Lake Sibayi, in Zululand,[1] a fresh water lagoon in a low coast plain; seeing that there has been recent elevation in South Africa, it seems very probable that this Zululand plain was one of marine denudation. At Port Elizabeth, the deposits on the raised plateau are manifestly marine. Why I am now led to favour the marine origin of the Uplands Plateau is because it is so narrow (see Fig. 12, p. 70), and it seems impossible that rivers from the steep mountains behind could, in the short course which the width of the plain allowed, come to such a quiet flowing stage that they were enabled to cut sideways and reduce the once rugged country to a more or less dead-level.

In Europe these continental ledges have been studied very thoroughly recently by Professor Hull, and, in his opinion, the submarine plateau that borders the northern continent was formed by wave action, on land emerging from the ocean. Notwithstanding its marine origin, this plateau between the Eng-

[1] 2nd Rept. Geol. Survey of Natal, London, 1904, p. 51.

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lish Channel and the Straits of Gibraltar carries gravel, sand, clay, and occasional mollusc remains. Similarly our 700 ft. plateau carries gravel, sand, and clay, now consolidated by surface hardening by infiltration of iron compounds and silica, and at Port Elizabeth carries wide areas of shells in a sub-fossil condition. If such high authorities as Profs. Hull and J. Giekie are content to regard the European continental ledge as a plain of marine erosion after the most exhaustive researches, it seems to me that when we have identical features reproduced in South Africa, we are justified in coming to similar conclusions. In Europe, the continental plateau is submerged 100 fathoms below; in South Africa, it is elevated 100 fathoms above sea-level. In the plateau whose margin is known as the Agulhas Bank, however, we have a ledge exactly resembling the European continental ledge; it is submerged 90 fathoms, and the dredgings of the S.S. Pieter Faure have brought to light boulders and sand 40 miles out to sea.

Off our coast we have, then, a succession of terraces, one of which is deeply submerged, and two others, taking the more pronounced ones only, elevated 700 and 1,500 feet. In the European ledge off Cape St. Vincent there is a similar succession of terraces, the lowermost going down to 200 fathoms, a condition which would be reproduced on our coast if the sea stood at the level of the Uplands Plateau. Between Morocco and the Canaries there is a broad terrace submerged between 600 and 1,000 fathoms, the whole movement in Europe pointing to a vertical displacement of over 8,000 feet. What I wish to emphasise is that it is proved in Europe that a succession of surf-cut terraces lie beneath the waters of the ocean; off our coast the same ledges exist, but most of them are above the level of the sea. Europe, then, is at the end of a long period of sinking; South Africa is towards the end of an equally long, if not longer, period of elevation. In Europe we notice the rivers running in wide channels, and the topography of the land generally is intensely dissected; in South Africa the rivers run in deep gorges, and the land surface is flat and plateau-like.

The deposits on these plains along the coast which we are describing are not characteristic, like those on the Swellendam Ruggens; the rock surface seems to have been bare, and to have gathered soil by disintegration, with the addition of blown sand. Over the greater portion of the plateau, whether cut in granite, Bokkeveld beds or Table Mountain sandstone, the soil is sour, and carries a layer of either "pot-clay" or ironstone gravel as a sub-soil.

The pot-clay is in most cases a fine, white, quartz meal, without any kaolin; it balls and moulds when wet exactly like a clay, but when it is attempted to burn it into bricks, the result is that the coherence of the particles is destroyed and the mass reverts to its true nature as a sand. Sometimes, however, where

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this "pot-clay" forms on granite or slate beds, then it does become a true clay—for instance, at Storm's River village—and under these circumstances it can be used for brick-making and even pottery.

The ironstone gravel is a peculiar deposit beneath the soil, forming a sub-soil between the rock and the true soil. It is formed by the coating of sand-grains by hydrated oxides of iron; sometimes this process results in the sand grains becoming separated, and a mass of rounded, shot-like particles are produced, usually of small size, and never larger than a walnut. At other times the whole becomes a sandy ironstone, all the material running together to form a continuous bank. Under the moist earth it is usually friable, but where the covering is removed, and it lies exposed to the surface, it becomes very hard, and forms a sheet of ferruginous rock, resembling a lava-flow;

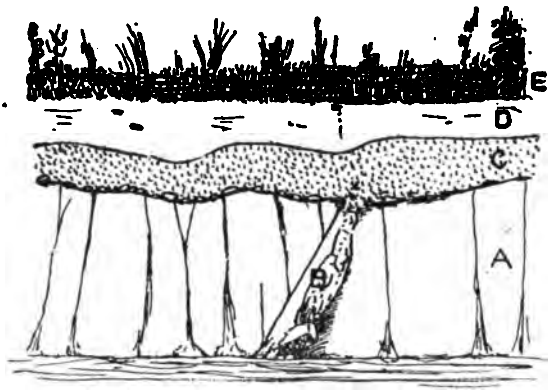

Fig. 15.—Section in railway cutting south of George Town, showing the formation of sour soil. A, Decomposed granite; B, Quartz-vein; C, Iron-stone gravel; D, Grey soil; E, Humus.

it then breaks up into quadrangular slabs by the slow desiccation and consequent shrinking. The depth of the deposit varies, but is seldom over two feet thick. In a wide sense of the term it might be called laterite, but there are little or no aluminous compounds where it forms on the Table Mountain sandstone or even on the George granite. It has formed by the rock disintegrating *in situ*, but owing to the want of drainage in the soil, the iron in solution in the water, which comes to rest above the hard rock, is deposited far in excess of the original constituents of disintegration (Fig. 15).

Where the ironstone is present the soil is sour, yet if the surface be tilled so that the air can penetrate, the sourness gradually disappears. On the granite, where the soil is thus rendered fertile, it answers admirably for orchards; the roots of the trees seem to penetrate beneath the ironstone layer, and to tap the

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loose granite beneath. If it were possible in practice to extract the granite and strew it on the surface, as is done in England, where soil on the Chalk becomes sour, and pits are dug, and the sub-soil brought on to the ground, the George sour-flats might be made very fertile.

Sour soil on Table Mountain sandstone cannot yield good results without artificially bringing on to it the necessary plant foods which are absent entirely from the disintegrated sandstone, the chief want being lime; round Knysna village the calcareous sea-sand to a certain extent near the coast brings this constituent naturally, and makes the soil sweet, but to the east along the flats before one reaches the Blue Krantz River, and beyond, in the Zitzikamma, there is no material near at hand which could supply the want, unless it is the calcareous shale in the Bokkeveld beds. It would be interesting and useful if this point could be cleared up; the shales would have to be analysed till one was found sufficiently rich in lime to be worth quarrying, and at the same time a suitable spot would have to be found where they could be advantageously brought up to the high-level plateau. As far as I am able to judge, I would advise that the shales about the mouth of the Storm's River should be examined, as there is already a wire rope-way established for hauling heavy material half-way up the hill, and the slates are well-exposed.

The blown sand commences again on the Rob-hoek,* where the grass begins to get mellow, and at Aasvogel Point and Zitzikamma Point, there are lofty dunes. Formerly these were covered with bush and the sand was prevented from scattering, but some 30 years ago, on the latter sand mountain, two bulls began fighting, and tore up the ground over a considerable area; the wind caught this bare patch in the bush, and gradually the loose sand spread, till to-day there are several miles of shifting sand where formerly there was excellent pasturage.

The soil on the Bokkeveld beds along the Keurboom's River is a lime soil, and very fertile; the steepness of the river banks makes much of this valley useless. The same soil is found in the slate outcrop that runs east from Storm's River.

There is also a third variety of soil besides the sour and the lime soil, namely, the brak soil; this is found in the estuaries of the Knysna, Bitou, and Groot Rivers, and is due to the accumulation of sediment in deep rock channels; it is also found along the Knysna lakes, but the calcareous sand makes it somewhat of a different character from the normal brak meadow-land in the open river estuaries. The brakness is quite different from the Karroo kind; it is caused by the common salt contained in the sea-water. Where the estuaries are cut in Uitenhage beds, as along the Knysna and Bitou Rivers, the gypsum

*Misspelt Roe-buck; the word means, Rob, a seal; and Hoek, corner.

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derived from these deposits neutralises the salt by a chemical interaction of the salts:—

$$CaSO_4 + 2\,NaCl = Na_2SO_4 + CaCl_2$$

The calcium chloride then combines with carbonic acid present in the humus, and liberates hydrochloric acid, forming lime. The process resulting in the change of the harmful common salt into the harmless sulphate, and the acid, being converted into a liquid form, easily drains away in the porous soil.

APPENDIX.

The Mineral Deposits of Knysna.

The mineral deposits in Knysna consist of the following:—In the Table Mountain series, gold, galena, and zinc-blende; and in the Bokkeveld series, pyrites, more or less cupriferous.

There is one fact which the whole of this investigation proved, that must be considered in dealing with this question, and that is, that the country rock of the known deposits of minerals was laid down after the first mineralisation of the strata had taken place; in other words, that what minerals these Silurian and Devonian rocks do contain has been derived from the disintegration of beds containing those minerals, and that they are not themselves traversed by veins filled in with minerals derived directly from deep-seated sources.

Where was the country rock derived from? There is little doubt now that the sediments were derived from a northern continent, the Table Mountain sandstone being formed close off-shore, and the slates farther out to sea. The relative positions of deposition, or the prevalence of off-shore and deep-sea conditions, was not simultaneous, but the one succeeded the other owing to the sea-bottom sinking.

From what we know of this northern continent, which existed in these Siluro-Devonian times, from an examination of the remains of it where it emerges from beneath the later covering of sediments in Namaqualand, Prieska, and the Transvaal, the rocks of which it is comprised contained many richly mineralised areas, the Rand banket and the Namaqualand copper ores being two instances.

The rivers flowing from this land would carry down such minerals that were exposed by the slow wasting of the land, and the heavier, less soluble ones would come to rest in the sandy off-shore deposits, while the muds and clays further from the land would receive the lighter and more soluble ones. I do not wish to insist on this gravity sifting, but it is certainly the case that gold and lead occur in the Table Mountain sandstone and the copper ores, which are very soluble, in the hardened mud now turned into the Bokkeveld clay-slates.

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The floor of Pre-Cape rocks in which these sediments were laid do not in this district show any sign of mineral wealth, so that we must look far afield for the origin of this mineral occurrence. The absence of metalliferous quartz veins in the Pre-Cape rocks is another link in the argument to prove that the metalliferous veins in the adjoining Cape formation have not derived their contents from a deep-seated source.

In the Table Mountain sandstone the major bulk, and it was very small in itself, of the gold, lead, and zinc, seems to have come to rest in a beach or gravel deposit that occurred near the end of the deposition of the series; this is now represented by a banket or quartz-pebble conglomerate, and occupies a position which elsewhere the shale-band occurs, and where also the Clanwilliam glacial conglomerate comes in. No official assay of this rock has been made, but I have heard it stated that it carries 2 dwt. per ton. In the Bokkeveld slates the copper and iron in solution became precipitated in among the layers of mud from which it slowly crystallised out, sometimes in pyritous layers, sometimes in cubes of pyrites. It seems rather far fetched to bring in the action of bacteria in this connection, but it has been definitely proved in the Black Sea that these minute organisms exist in the waters, and have the power of secreting pure sulphur; when they die the sulphur, minutely divided, combines with the iron and copper in solution in the water, and these are precipitated as sulphides in the mud collecting on the floor of the lake.

This, then, has been the first stage in the mineralisation of these beds, the ores are distributed in among the sediments.

The second stage occurred when the crushing of the beds, after being laid down, took place. As we have previously seen, this thrust was brought up against the inland sides of the great granite bosses, and where these end, there was a tendency to flow round the termination; in other words, there was produced a tension in the neighbourhood of the end of the granite, whereas the rest of the country rock was under pressure. The tension was relieved by the beds cracking. Into these fissures water, containing silica and metallic substances in solution, gradually leaked. It has been proved experimentally that under great pressure even at low temperatures many substances pass naturally into solution, which under atmospheric pressure are almost entirely insoluble. At the same time, substances like gold and silica become soluble when there are minute traces of certain salts in the water; free chlorine and ferric sulphate in solution act upon gold, and salts of the alkalies on silica. Both these causes were present to abstract the quartz and metallic substances from the banket and sandstone beds, and the liquid naturally passed from areas of pressure to the open cracks, and in that way slowly filled these up with the re-deposition of the dissolved constituents. According to the ratio between the

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dissolvent salts, much or little gold accompanied a given quantity of quartz in its deposition in the fissures, so that in some instances quite a rich reef became built up, and in others, only barren reefs. From a study of the actual reefs in the Millwood area, it is seen that besides the substances like gold, galena, and blende, with the silica, that are deposited from water, there must have been in the initial filling of the fissures a good deal of material carried mechanically into them, for the quartz reefs are often veined and coated with a glistening, slaty material. In the Bokkeveld area, however, the quartz reefs are massive, white quartz, without any foreign admixture, except the copper and iron pyrites.

In the Table Mountain sandstone, about Millwood the reefs are much divided and splintery, as if the formation of the fissures were due to a tearing action; we may, perhaps, refer this to the varying tensile strengths of the sandstone beds, which have in that respect a more diverse constitution than the slates and calcareous or argillaceous sandstones of the Bokkeveld series. In the latter the fissures are clean cut, and the white quartz fills in the whole from wall to wall.

As regards the vertical extent of these reefs, we find them at the following altitudes above sea level:—

Hickfang's mountain reef...	2,600	feet.
Temperance	1,860	„
Central...	1,600	„
Bendigo...	1,560	„
Bella	1,360	„
Milne...	1,310	„
Oudtshoorn	1,210	„ *

These are all in Table Mountain sandstone; in the Bokkeveld beds we find them in the Little Homtini at a couple of hundred feet above sea level. Considering that the present surface of the land is not an original one, but has been formed by the removal of immense quantities of material by denudation, the original upward extent of the reefs above sea level may be safely stated to have been twice that which they now attain, namely, 5,000 feet, and since the reefs that are seen near sea level along the Little Homtini show every sign of continuing indefinitely downwards, the reefs at Millwood may be expected to reach at least a thousand feet below sea level. The question whether any particular reef will reach down to the extreme depth is only to be found by actual working, and a prospector on the spot should be able to see whether the reef shows signs of pinching out, or whether it is likely to last with depth. Even should the reef pinch out with depth, I am inclined to think that it will come in again lower down, as these reefs are the results of shells

* I am indebted to Mr. P. Fletcher's Report, G. 17—'91, for these figures.

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of tension, which occur at given distances from the granite; the direction of the reefs is determined by the strength of the rock, but their extent is determined by depth to which the tearing force has acted.

In regard to the gold content of the reefs,—we can confine ourselves to this particular ore as the arguments for the galena and blende would be the same,—we have two factors to consider, surface enrichment and permanent content. The latter is determined by the circulation of water bearing gold in solution, and this again is determined by the depth of the strata containing gold, which we have reason to believe are the banket reefs. The banket dips steeply south just below the junction of the Millwood creek and the Homtini, and comes up again along the Homtini on the south side of the Bokkeveld inlier; it must, therefore, pass beneath the Bokkeveld beds, and thus attain a depth of a couple of thousand feet at least beneath sea level. Circulation of water through the substance of the rocks will go on wherever there is pressure in one place and an open space in another, and, therefore, will be active along the whole length of the quartz reefs from top to bottom. As the solution of the gold depends partly on pressure it is reasonable to suppose that the gold content of the water will be larger the deeper it circulates, and as a result the gold reefs will be richer at greater depths than they are found to be at the present surface. We must remember in this connection that we are dealing with infilled veins, and not with a stratified ore body like the banket; in the latter case one would expect the gold content to be independent of depth, while in the former case the solvent power of water under increased pressure has full play to exert its influence.

The surface enrichment of quartz veins may be considered as part of the third stage; the second stage in the mineralisation of the rocks being the leaching out of the gold and deposition of that mineral with quartz from solution in suitable crevices.

As the surface of the ground weathers away the reefs containing gold are exposed, and themselves slowly crumble away. The gold in the disintegrated portions being very heavy, tends to remain where it is, but the surface water is not pure water, but contains certain salts which act strongly upon gold.

The first and most natural solvent of gold that might occur is free chlorine. The water of Millwood is strongly tinged reddish brown from washing through the rank, marsh soil, and it is known that plant roots elaborate to a certain extent hydrochloric acid; the latter is not itself a solvent of gold, but it is quite possible that to a certain extent free chlorine may exist with the acid, and in that case a strong solvent solution would result.

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Other solvents are sodium and potassium chloride,[1] sodium silicate,[2] sodium sulphide, sodium sulphydrate, and sodium carbonate saturated with sulphydric acid.[3] Doelter has found that gold is soluble in sodium carbonate and sodium silicate heated in iron tubes to 200° to 250° C.; when the experiment had continued for 47 days, the tubes were opened and small aggregations of gold crystals were found imbedded in a mass of crystalline and globular quartz.[4]

Recently Atkin has suggested that the more probable natural solvent of gold is ferric sulphate, which, on reduction to ferrous sulphate, immediately precipitates the gold.[5]

At Millwood the supply of this ferric salt would be far in excess of all the others put together, since the blue colour of the Table Mountain sandstone, as it exists in the unweathered state, is due to sulphides of iron, whereas sodium compounds are absent from the formation traversed by the streams. There may, of course, be other solvents which can act when years are allowed for the process, and when tons of material are exposed, which cannot be examined in the test tubes of the laboratory, but as ferric sulphate can dissolve the gold and is present in the waters, it does not seem that one need seek further for a solvent salt.

In ordinary storms the water falls heavily upon the surface of the ground and a certain amount of gold might be carried a short way mechanically, but the major portion of the water would flow away so rapidly that it would not have time to absorb salts from solution. When the rain had passed, then the residual portion of the water that had sunk into the ground would begin to percolate, and as the time from the original precipitation became longer and longer, the passage of the water would become slower and slower. In the later stages of drought the water would become comparatively strongly charged with the ferric sulphate. All cracks, crannies, and hollows of whatever nature would now draw in this water, which, having passed slowly over the quartz reefs, will have had time to dissolve a certain amount of gold; especially favoured parts like the joints in the sandstone would hold this water, and on evaporation the gold would be precipitated. The quartz reefs themselves, where they have become broken up on the surface and have had part of their substance already washed away, would likewise be convenient places for this water to settle, and consequently the surface of the reefs would become re-charged with gold even on a more plentiful scale than originally.

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[1] Egleston, Trans. Am. Inst. Min. Eng., 1880, VIII., p. 455.
[2] Liversidge, Proc. R. Soc., N. S. Wales, XXVII., 1893, p. 303.
[3] Becker, Mon. U. S., Geol. Surv., XIII., 1888, p. 433.
[4] Chemische Mineralogie, Leipzig, 1890.
[5] The original papers of Le Conte and Wurtz are not available; they are quoted by Mr. Atkin, Q.J.G.S., 1904, LX., p. 390.

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It is an interesting speculation whether the two forms of nuggets, the rounded and the sharp-edged, may not be caused in the one case by sudden precipitation, due to the reduction of the ferric salt to the ferrous, and in the other by the slower process of evaporation.

I do not wish to maintain that no gold is carried down mechanically into the stream beds, but what I think the facts point to is that the larger proportion of nuggets found are derived from chemical solution and precipitation.

The following are the chief factors in arriving at this conclusion:—

1. The nuggets of gold are found in between joints and under ledges of rock associated with fine mud; if they had been carried into these positions mechanically, it is hard to explain their presence when the matrix they lie in is of so much lighter material.

2. The nuggets are often of large size, and it is never found that the gold in the quartz veins is in nugget form.

3. The nuggets are of very varying appearance, some being apparently water-worn and rolled, others are quite fresh, with sharp edges, and cannot have travelled any distance from their original position.

4. Gravelly hollows in the stream bed, after being worked out, become after a few seasons filled again with gold nuggets, though the reefs about the stream banks are known not to contain nuggets.

5. The theory of chemical solution and precipitation adequately explains all known facts.

As regards the ores associated with the gold, namely, blende and galena, it very frequently happens that these two minerals accompany the precious metal; for instance, in Merionethshire, in Wales, gold quartz veins, sometimes with calcite, carry iron pyrites, copper-pyrites, zinc-blende, and galena; in Chota Nagpur, gold quartz carries iron pyrites, arsenical pyrites, and galena; Western Australia gold quartz carries iron, copper and arsenical pyrites and galena; California gold quartz carries iron pyrites, blende, galena, arsenical and magnetic pyrites, copper pyrites, and cinnabar; in Takon, Alaska, gold quartz carries ores of silver, lead, copper, and zinc: in Andacollo, Chili, gold quartz carries iron, copper, and arsenical pyrites, blende, stibnite, and galena. Instances might be multiplied indefinitely, but the frequent association of these three minerals, gold, galena, and blende, is sufficiently indicated in the above list; it would be a work of great interest if the full mineralogical content of the Millwood reefs could be worked out.

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Most of what I have said relative to the passage of ores from the surrounding rocks into fissures which are filled with quartz contemporaneously with the mineral deposition, in reference to the Table Mountain sandstone region, applies to the Bokkeveld area, only here the ores, copper and iron pyrites, are not massed in a particular band, but were disseminated originally throughout the series. With these pyrites reefs, however, there is no subsequent enrichment in the sense of the third stage of the process of gold formation.

In conclusion, the examination of the Millwood area has led me to trace the original seat of the gold to the banket beds; the precious mineral is leached out of this and deposited in quartz veins. These latter are sometimes extremely rich on the surface, but are poor in the bulk.* All estimates of the value of these reefs must, however, be taken with great caution, as no work has been done on them systematically; the failure of most of the companies hitherto working in the area has been due to reckless mismanagement, and in addition, when at last legitimate work was commenced, the Witwatersrand banket was discovered, and all available capital was invested in the Transvaal. There is reason to believe that the reefs will improve in value with depth. Although the Millwood reefs are low grade, as far as I was able to judge, they ought to repay working under competent management, owing to their favourable situation in regard to nearness to the sea-board and abundance of water and wood in the vicinity. If one-hundredth part of the money which has been squandered on these fields had been employed for the set purpose of proving or disproving the payable nature of any one of the reefs under experienced guidance, I have no doubt that a large industry would have been established there for a long time now, but with the hundreds of thousands that have been spent there, we are still ignorant as to whether any single reef will repay working or not. The recovery of the alluvial gold spread out on the gravels on the Poverty Flats and in the estuaries of the Knysna and Homtini (Gouwkamma) Rivers should be worth attempting in view of the enormous quantity of country rock riddled with gold-bearing quartz-veins that has already been disintegrated and washed down from the Millwood area, it matters not in this respect whether the gold was carried mechanically or in chemical solution.

* I was told that a trial crushing of the Oudtshoorn reef gave 2 dwt. over the plates, and 2 dwt. in the tailings, but there is no record of what was put into the battery, whether picked reef or reef and country rock together.

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Return of Gold Registered at Millwood.

	oz.	dwt.	grs.
1887	335	11	21
1888	448	13	11
1889	113	17	14
1890	300	16	5
1891	406	8	5
1892	442	19	9
1893	244	4	12
1894	166	13	4
1895	22	—	—
1896	94	—	—
1897	43	—	—
1898	113	9	6
1899	130	16	16
1900	125	18	21
1901	78	0	0
1902	25	18	12
1903	12	2	4
1904	36	11	15
1905 ... ... (up to March).*	29	6	16

*** From 1887 to 1894 the returns are published in the reports of the Inspector of Mines; from 1898 to 1900 in the Reports of the Conservators of Forests; the other figures I obtained from the Agricultural Department, through the courtesy of Mr. B. McMillan.**

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GEOLOGICAL SURVEY

OF

GLEN GREY, AND PARTS OF QUEENSTOWN AND WODEHOUSE, INCLUDING THE INDWE AREA.

BY

ALEX. L. DU TOIT.

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THE GEOLOGICAL SURVEY OF

GLEN GREY, AND PARTS OF QUEENSTOWN AND WODEHOUSE,

INCLUDING THE INDWE AREA.

I. Introductory.

The area surveyed is approximately 2,400 square miles in extent, and consists of the southern portion of Wodehouse (all to the south of the main watershed), the whole of Glen Grey, and the greater portion of Queenstown, the limit being the Zwart Kei River, and thence across to St. Marks.

Special attention was given to the Indwe and Sterkstroom areas, because of the economic importance of the coal deposits and on account of the geological difficulties encountered.

The divisional map of Glen Grey, on the large scale of 400 Cape roods to the inch, proved satisfactory for the work; that of Wodehouse, on half the above scale, was so untrustworthy that it had to be entirely redrawn; while in the case of the Indwe area a special large scale map was constructed in the field.

The area examined is drained entirely by rivers flowing into the Indian Ocean:—the Indwe, Cacadu, White Kei, Klaas Smit's, and Zwart Kei Rivers, all tributaries of the Great Kei.

On the north is the watershed of the Stormberg, forming a fine escarpment near Sterkstroom. South of Dordrecht the divide is by no means pronounced, but north of Indwe the valley of the Doorn River is separated from that of the Waschbank by a lofty spur of the Drakensberg, which attains an altitude of 6,700 feet above sea-level.

The country is very mountainous in the northern portion of Glen Grey and to the east of the Indwe River. Along the Queenstown boundary, east of the railway from Sterkstroom to Lesseyton, the high ground culminates in the rugged dolerite mass of the Andriesberg. An extension of this ridge is the dolerite-crowned mountain Hangklip (6,700 feet), overlooking Queenstown. In the southern portions of Queenstown and Glen Grey, prominent ridges of dolerite traverse the country in various directions, but westwards, and away into Tarka, we find the typical Karroo scenery, wide flats with isolated ridges and peaks, often table-topped and crowned with dolerite. The whole area is thickly covered with grass in the summer time; towards the south and south-east there is an abundance of mimosas and aloes.

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The Formations.—The strata met with belong either to the Burghersdorp (Upper Beaufort) or to the Molteno Beds; the higher strata, Red beds and Cave sandstone, are of limited extent in this area. The beds lie nearly horizontally, but there is a general slight northerly dip. Dolerite intrusions penetrating the sedimentary rocks occur on a very large scale, and have produced great dislocations and disturbance in the strata, in fact, almost invariably the beds on opposite sides of a dolerite sheet are displaced.

II. The Burghersdorp Beds.

Rocks belonging to this sub-division of the Beaufort series form the whole of the southern and south-western portions of the area surveyed. The maximum thickness of this formation as yet mapped is between 2,000 and 2,500 feet, the lowest strata appearing along the valley of the Zwart Kei, between Kamastone and Tylden. Further to the south-west, the general surface of the country rises once more to form the Great Winterberg Range, and it is probable that some of the higher strata re-appear in that direction.

Throughout this great thickness of material, the formation maintains a wonderful lithological uniformity, though the strata at Tylden are slightly different in character, indicating that the base of this sub-division of the Beaufort series is being approached. The Burghersdorp beds in this area have characters identical with those of the beds of the same formation in Aliwal North, described in the last Annual Report (pp. 77-82).

In the latter area only a small thickness of strata was exposed, chiefly the somewhat variable zone of transition into the Molteno beds. In this part of the Colony it was found that after a distance of from 100 to 200 feet below the base of the overlying formation, the strata become perfectly regular and uniform, so that, from the lithological characters alone, it is impossible to determine the actual stratigraphical horizon of any particular stratum.

While the Molteno Beds constitute a formation which is essentially arenaceous, the Burghersdorp Beds belong to one which is practically argillaceous. The sandstones are usually of no great thickness, and are light coloured, fine grained, and felspathic; often the quartz grains show secondary enlargement and crystal faces, so that the sandstone has a tendency to sparkle in sunlight. Some of the thin ribs weather into rounded lumps, like the fine-grained hard sandstone layers around Beaufort West.

The softer rocks often form layers over a hundred feet thick, and consist of mudstones, with thin bands of friable sandstone of deep reddish, violet, or purple colour, commonly alternating with greenish varieties. Mottling is very frequent. Calcareous

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bands are not uncommon, and calcareous matter may be present in sufficient quantity in some of the mudstones to justify the name of "marls" being applied to them.

The water derived from rivers flowing over, or wells sunk in, the Burghersdorp beds is always hard, and in some places distinctly brackish. One marked example is a small stream in Glen Grey, crossed by the road from Driver's Drift to Bolotwa. Salt water was obtained in one of the boreholes put down in the village of Lady Frere.

Fossils occur in the Burghersdorp beds at a number of points. Plant remains have only been found in the sandstones, and are therefore rather badly preserved; bones occur both in the sandstones and the mudstones.

Although the distribution of the reptiles is not yet very well known, it appears that the upper portion is characterised by the presence of theriodonts, *e.g.*, *Gomphognathus* and *Cynognathus*, while from the lower *Procolophon* has been obtained.

At Indwe.—Commencing with the description of the Burghersdorp beds at Indwe, we find that along the Doorn River there is usually a great thickness of alluvium, and that the purple clays and shales are exposed only at a few points.

Deep dongas or ditches are being cut in this alluvium, and in this connection, attention may be drawn to an article* by Mr. G. E. Dugmore, M.L.A., on the erosion in this locality. At only one point is the junction of the purple rocks with those of the Molteno beds seen, but from borehole records the boundary line on the map has been located.

The Doorn River flows through a narrow "poort," about three miles south of Indwe. This is an excellent site for a dam, as was long ago pointed out by Mr. T. Bain (**13**, 18), and it is to be hoped that such a scheme may be carried out in the future, either by the Indwe Company or by the Town Council.

South of this stretches a considerable flat, over which outcrops of rock are infrequent. On the banks of the Doorn River, at the drift on the road from Indwe to Lady Frere, thin sandstones, with dark mudstones and shales, occur, including one reddish band of no great thickness. Some of the mudstones are crowded with small irregular dark nodules, which are hollow and filled with variously-coloured ochres. There is a marked local unconformity here, and in one place a bed of sandstone, for a distance of several hundred feet, rests horizontally upon the eroded edges of strata, dipping at an angle of about fifteen degrees.

These beds may be placed at the extreme base of the Stormberg series, for farther to the south and south-west the typical purple sandstones are well exposed; on farm, No. 6B, Block 3, a borehole penetrated about 100 feet of the latter without encountering any sandstone.

* Agricultural Journal of the Cape of Good Hope, March, 1905, p. 375.

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South of "Trennery's" (Indwe Poort), the Burghersdorp beds form a wide grassy flat, divided into two portions by the low dolerite ridge which constitutes the boundary between the Divisions of Wodehouse and Glen Grey. South of this extensive fertile flat the ground rises again, but the sedimentary rocks are to a great extent altered by dolerite.

In Glen Grey.—The Bengu basin is hemmed in by smooth dolerite hills, and all the drainage is directed eastwards into the Indwe River. Close to the trading station of Bengu there is a peculiar outcrop of white-weathering shales, and soft, slightly-spotted sandstones, reminding one very much of the "white band" of the Dwyka formation. These white or pale leaden-grey beds appear to pass laterally into rocks with a purplish tint; nowhere else was anything similar noticed.

The town of Lady Frere is situated at an altitude of about 3,400 feet above sea-level, in a basin-shaped area on the left bank of the Cacadu River. On the north-east rises the great mass of the Donga mountain (5,800 feet), while to the north-west is Mount Arthur (6,070 feet), both of which elevations turn precipitous faces towards Lady Frere.

The Donga Mountain forms a vast amphitheatre, the edge of the cliff face being formed by the Indwe sandstone, overhanging in many places; at one point, there is an immense cave.

From Lady Frere upwards there is exposed a vertical thickness ot 1,400 feet, or allowing for dip, about 1,600 feet of Burghersdorp beds. The strong contrast between this formation, with its thin sandstone layers and thick interbedded purple mudstones, and the massive sandstones of the Molteno series, is never better seen than on the eastern extremity of the amphitheatre. The Molteno beds form a precipitous face of almost solid sandstone, about 1,000 feet high. Huge masses of sandstone strew the base of the mountains, among which blocks of the coarse pebbly Indwe sandstone are conspicuous. Very noticeable, too, are the number of quartzite boulders which have weathered out of the Molteno sandstones.

The Donga Mountain is merely a shell of sedimentary material, the core, of dolerite, being formed by a highly-inclined sheet, which is exposed in the various kloofs and also on the east and west. The purple mudstones near the contact with the dolerite have for a considerable distance from the junction been altered to hard and splintery buff or terra-cotta coloured rocks, with the development of a rude columnar structure.

A rather thick sandstone caps several extensive plateaux around Lady Frere. This sandstone is light bluish-green when fresh, but weathers to a yellowish brown colour. It must be fully 60 feet thick, and has been extensively quarried for building stone. From it were obtained badly preserved fronds of *glossopteris* and striated and *lepidodendroid* stems; also two large fronds of a plant that has not yet been identified.

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The thick purple shales and mudstones often include hard greenish-grey sandstone ribs, from an inch up to a few feet in thickness. Purple sandstones are not very common, and are in thin bands. Reddish limestones are rare, but there are abundant light-coloured calcareous concretions of very irregular shape, while small septarian nodules are frequent.

From Lady Frere a quantity of reptilian remains, principally those of theriodonts, were obtained by Sir Bisset Berry, Mr. T. Bain, and Prof. Seeley, the specimens being described by the latter† :—

Gomphognathus polyphagus.
Cynognathus Berryi.
Cynognathus crateronotus.
Trirachodon Berryi.
Tribolodon frerensis.
Also an *anomodont* carpus.

A large number of boreholes have been put down within the town of Lady Frere, all of which have struck water at a moderate, though varying depth. Some of the boreholes give off odourless inflammable gas, probably "marsh-gas." One of the wells evolved a large quantity, but the supply is gradually diminishing. The gas is undoubtedly derived from a certain horizon in the purple mudstones, and not from the base of the alluvium, which is here up to 30 feet in depth.

Burghersdorp beds crop out on the low ground in the wards of 'Mkapusi, Buffeldoorns, and Vaalbank, in the north of Glen Grey. This large basin-shaped area is almost entirely surrounded by dolerite ridges, except to the north of Kapusi Mountain, where an escarpment is formed by Molteno beds. Alluvium covers a large portion of the floor of this basin; at Buffeldoorns trading station the White Kei has cut its way through about 25 feet of sand and gravels, while numerous dongas or ditches are in the course of formation in the neighbourhood.

To the north, north-west, and west the strata have been faulted down, so that the rocks exposed in the gorges of the Birds' and Buffeldoorn's Rivers, which rise in Wodehouse, and in Zwart Water, belong to the Stormberg series.

In the Qoqodala basin a sheet of dolerite exists just below the surface, and in consequence, there are everywhere patches of highly indurated and often columnar and prismatic sandstones and mudstones. The latter have been altered to a blue-black flinty material, chips and flakes of which strew the ground in considerable quantity.

The sides of this basin are formed by dolerite, and the intrusion extends eastwards into the ward of Agnes.

† H. G. Seeley, Phil. Trans. Roy. Soc. London, Vol. 186, part IX, sects. 4 and 5, 1895.

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South of Driver's Drift, along the banks of the White Kei, there is an abundance of flinty gravels, the material having been derivea from the wards of Qoqodala, Agnes, and Nonesi. The main road from Driver's Drift to Queenstown crosses Nonesi's Nek, the rise being a little over a thousand feet; very fine sections are exposed along the road cuttings (see also Molyneux's description, **5**, 25). About four miles due east of Driver's Drift some reptilian remains were obtained, embedded in nodules of hard calcareous sandstone.

These include the posterior portion of a skull of *Gomphognathus polyphagus*, Seeley, which unfortunately wants the snout; and a portion of a reptilian occiput, possibly anomodont.

Along the White Kei, the shales and mudstones have a tint approaching violet, rather than purple. Bands of whitish or very pale blue arenaceous mudstone are frequent, also greenish shales and mudstones.

In the wards of Lante, Mbinzana, Bolotwa, and Macibeni,§ the Burghersdorp beds maintain their normal characters. At St. Marks (2,675 feet) and Tylden (2,890 feet), where the lowest beds yet examined crop out, there are differences. The sandstones are thicker and more abundant, and are often of a pink or lilac tint; shales and mudstones are not well exposed. Records of boreholes in the adjoining division of Cathcart, and in Queenstown, south of the Zwart Kei, show that the ratio of the proportion of sandstone to shale increases continually as the strata are followed towards the south.

In Queenstown.—The strata lie in an almost horizontal position around Tylden, and close to Whittlesea, but Dunn (**2**, 18) states that between the latter village and the Katberg the beds dip towards the south. It is therefore very probable, in view of the changes noted above, that the formation as a whole becomes more arenaceous towards the south. The area southwest of Kamastone has not yet been surveyed, but Stow (**1**, 526) has given a good description of the rocks around Tafelberg. The fossils from this locality include the theriodont *Galesaurus planiceps* (*Nythosaurus larvatus*, Owen),* and the labyrinthodonts *Micropholis stowii*, Huxley,† and *Micropholis granulata* (*Petrophryne granulata*, Owen)‡; while from the farm Donnybrook, a little to the south of Tafelberg, come numerous specimens of *Procolophon trigoniceps*,** Owen, and also the skull of a lizard *Paliguana Whitei*, Broom.||

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§ It is important to note that there are two wards, one Macibeni and the other Macubeni, in the south-west and north-east corners respectively of Glen Grey.

* Cat. Foss. Rept. and Amphib. Brit. Museum. Part IV, p. 70, 1890.

† Quart. Journ. Geol. Soc. Vol. XV, p. 649, 1859.

‡ Cat. Foss. Rept. and Amphib. Brit. Museum. Part IV, p. 174, 1890.

** R. Broom. Records of the Albany Museum. Vol. I, no. 1, p. 9, 1903.

|| *Ibid*, p. 1.

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Between the Zwart Kei and Queenstown are several annular ridges of dolerite, with intervening grass-covered flats.

At Queenstown itself are a few thin beds of sandstone, which furnish a building-stone of excellent quality. The principal quarry is situated to the north of the town, just beyond the Hospital. The stratum worked is a bed of very close-grained sandstone, bluish-green in colour and brownish-yellow when weathered. False-bedding is not uncommon, and is often at a high angle.

The portion of rock removed does not exceed eight feet in thickness, and of this a considerable amount has to be rejected owing to the inclusion of irregular patches and lenticles of green or blue shale, which may be present in such abundance as to produce a clay-pellet conglomerate. The clay-pellets are often of nearly uniform diameter, about the size of a pea or bean, and the peculiar fragmental rock produced may occur in layers of as much as three feet in thickness. Small lumps of calcareous material may be included, and on weathering, the rock becomes a porous mass. Small rolled fragments of bone are of frequent occurrence in these conglomerates. In the sandstones fragmental remains of plants occur very sparingly, and are nearly always portions of striated stems, probably those of *Schizoneura*. As a building material, the Queenstown stone is noted throughout the Colony, but there appears to be no reason why the sandstones of this formation in other parts of the Eastern Province should not be utilised too. Good stone has been obtained at Lady Frere, Driver's Drift, St. Marks, and many other places; it is therefore very likely that along the railway, at points between Rosmead and Steynsburg, excellent building stone can also be found.

The sandstone bed at the summit of Bowker's Kop, a small detached elevation overlooking Queenstown, is in places impregnated with the hydrated carbonates of copper. On the ridge forming the southern boundary of the Lesseyton Commonage, there is an outcrop of highly altered shale and sandstone adhering to the upper surface of a sheet of dolerite. The sedimentary and igneous rocks are firmly welded together, and development of epidote has taken place in the former, accompanied by minute quantities of pyrites, galena, and bornite.

About four miles north of Queenstown, at the head of a small valley, there is a prospecting shaft, which has been sunk on a narrow dyke or inclined sheet of dolerite. The strata in contact with the igneous rock are much brecciated, and in the middle of the dolerite itself, which is not more than two feet thick, there is a band of brecciated rock, cemented by quartz and calcite. Assays have not given encouraging results. Close by, on the ridge to the north-west, some fragments of bones were obtained by Mr. Martindale, of Queenstown, the horizon being about 1,000 feet below the base of the Molteno beds.

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These, Dr. Broom states, probably belong to a species of *Dicynodon.* It is of interest, because Dicynodon has been found in the same formation at Burghersdorp.*

In the Bongolo Valley, on the ascent of the Nek leading over into Qoqodala, there are fine sections of the Burghersdorp beds along the roadside.

At one point, where a considerable thickness of mottled purple mudstone is overlain by a solid bed of sandstone, the under surface of the latter is crossed with irregular ridges, while cracks are filled in with pink limestone. The basal portion of the sandstone is conglomeratic, with pellets of green and purple shale, limestone, and often abundant rolled fragments of reptilian bones. Evidently the surface of the mudstone represents an old mud-flat, on which pellets of clay and bones were rolled about before being covered up by coarse sediment. Stow (**1,** 544) mentions a peculiar "whirled sandstone" on the Bongolo Nek, but the only rock visible at the summit is a sheet of decomposed exfoliating dolerite, overlain by thick reddish-black soil.

North of Queenstown, the ridge constituting the divisional boundary is crowned with Molteno beds and overlying dolerite, outliers of the same occurring on the peaks Hangklip and Ben Hepburn.

Opposite the Zwart Water Location, the strata dip rapidly to the north, so that the Molteno beds are found in the valley just north of the police camp at Hill End. All the high ground westwards, to within less than a mile from the railway, is formed of rocks belonging to the Stormberg formation, the junction with the Burghersdorp beds on the south-east and south-west being concealed by dolerite intrusions.

From the railway, the surface of the ground slopes gradually westwards to the Klaas Smit's River, forming flats which stretch to the base of the Stormberg escarpment, a considerable distance away. This tract of flat ground is divided into two portions by a great double intrusion of dolerite on Doornhoek and Uitzigt, dipping south-eastwards, and giving rise to the towering masses of the Wildschuts Berg on the Tarka border.

Through this ridge the Klaas Smit's River has sawn a deep and narrow channel, nearly a mile in length. Surveys have shown that a retaining wall could be thrown across the stream in this "poort" at a comparatively low cost, and that the water impounded would cover many square miles of flat country to the north.

North-west of Putter's Kraal station the Tarka boundary, from the Stormberg escarpment as far as the main road from Sterkstroom to Tarkastad, is formed by a narrow spur of Molteno beds. The Burghersdorp beds cover wide flats, and extend up

* R. Broom. Annals of the S. Afr. Museum. Vol. I, part 3, 1899, and Proc. Zool. Soc. London. Vol. II., p. 86, 1902.

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the Haasje's Kraal Spruit as far as the farm Wilge Kloof. To the north, along the foot of the Stormberg escarpment, as far as Bushman's Hoek, the purple mudstones and shales are fairly well exposed, and the base of the Molteno beds can generally be fixed to within about 50 feet. Especially fine sections are seen in the deep narrow kloofs at the head of the Buffels Kloof Spruit, a bird's-eye view of which is obtained during the descent by rail from Cyfergat to Sterkstroom.

III. The Molteno Beds.

Molteno beds cover almost the whole of the south of Wodehouse, and also small areas in the north of Queenstown and Glen Grey. There is a general rise of the strata towards the south-west, so that in the central and southern portions of the two latter Divisions outliers of Molteno beds cap the highest elevations only.

The formation is essentially arenaceous, more so in this area than in the country to the north; but this fact is not usually manifest, except from a study of boring records. However, at Lady Frere, as mentioned earlier in this report, and at Mount Arthur, Hangklip, Zwaart Water, Bushman's Hoek, and on the Tarka boundary, the great development of sandstone is very clearly seen.

The sub-divisions of the Molteno beds proposed in the Report on the Divisions of Elliot and Xalanga,* can, with slight modification, be adopted for the area west of the Indwe River also. The *Indwe sandstone* is the most important sub-division, and its boundary has been mapped throughout this area, but the higher members are not so easily recognised. The *Gubenxa sandstone* can, in a few places, be identified, but the Molteno beds are so often disturbed by dolerite intrusions and patches of the formation isolated, that it is often impossible to be certain about the higher horizons. The sub-divisions are as follows, using the same numbers as in the 1903 Report:—

- 9-6. White sandstones, with thick beds of pebbly and "glittering" sandstone, bands of dark mudstone and shale, and occasionally thin coals.
- 5. Coal horizon (Cala Pass, Tarka, etc.).
- 4. Soft fine-grained sandstones.
- 3. Indwe sandstone, coarse and pebbly, with ironstone nodule band.
- 2*b*. Guba coal horizon.
- 2*a*. Fine-grained bluish grey sandstone, about 80 feet thick.
- 2. Indwe coal horizon.
- 1. Fine grained grey felspathic sandstones, with thin beds of grey and buff shales and mudstones.

* Ann. Rept. Geol. Comm. for 1903, p.175.

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There is a general thickening of the Molteno formation towards the south and south-east. Thus the strata below the Indwe sandstone have a thickness of from 150 to 250 feet in Aliwal North, 450 to 500 feet at Sterkstroom and Indwe, 700 feet at Cala and at the head of the Guba River, and about 1,000 feet at Lady Frere. The total thickness of the formations varies in a similar manner, *e.g.*, 1,000 to 1,200 feet in the north, from 1,200-1,400 feet along the south of the Stormberg, and 1,900 feet in Elliot. Apparently the Red beds, and usually the Cave sandstone, vary similarly.

For convenience in description, the tract occupied by the Molteno beds will be divided into three sections:—(i.) the Indwe area (*e.g.*, that included in the map accompanying); (ii.) the area lying to the west and south-west of Dordrecht; and (iii.) the Sterkstroom area.

(1). *The Indwe Area.*

The Indwe centre is one of the most important of the coal-producing areas in the Cape Colony. Although the existence of the seam had been known for many years, and although the reports of various experts engaged by the Government had been very favourable, yet nothing was done until the Indwe Railway and Collieries Company constructed a line from Sterkstroom to Indwe. The township of Indwe sprang into existence, and although no more than twelve years old, is already larger than Dordrecht. The output of coal from the Indwe mines has been fairly constant, as will be seen from the following table*:—

1897	51,218	tons.
1898	107,497	„
1899	132,603	„
1900	129,009	„
1901	129,819	„
1902	116,154	„
1903	133,584	„
1904	108,021	„
1905	82,220	„

The area at present being mined, known as the "Camp," is roughly triangular in plan, with its apex directed to the south, each side having a length of about one and a half miles. This triangular area is crowned with the Indwe sandstone, and the coal crops out just below the escarpment bounding the plateau. There is a general dip of nearly two degrees to the north-north-east. The continuity of the seam along the hillside has been

* I must acknowledge my indebtedness to Messrs. G. Dugmore, M.L.A., and W. Whitaker, Directors of the Indwe Collieries, and to Mr. J. Colley, Mine Manager, for abundant information, and for permitting me to examine the plans and boring records.

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proved by a number of openings, but the coal is being worked from four drives only, *e.g.*, the Byrne mine (on the west), the Green mine (on the south), the Dugmore mine (on the east), and the Milner mine (between the last two, but closer to the latter). The old workings, known as the Spriggton mine, are in the very apex of the mining area, but this portion has all been worked out. There are a number of dolerite dykes crossing the field, which have to a considerable extent determined the area that can be worked from each of the four openings. In both the Byrne and Green mines the dip of the seam in the workings is away from the outcrop, and therefore the grade is adverse to haulage and drainage.

In the Dugmore mine, which has the largest output, there is a complete electrical haulage, both under and above ground. A tramway has been laid along the hillside, round to the Green mine, and the output from the latter is now being drawn by electrical locomotives to the screens at the Dugmore mine.

It is the intention to extend this tramway round to the Byrne mine, so that in the future all the coal mined can be taken to the Dugmore mine, and there screened and mixed, so that a perfectly uniform product may be obtained

There are a number of shafts from 150 to 200 feet in depth on the plateau by which ventilation is provided. A large number of borings have been put down with the diamond drill, and the continuity of the seam proved within the area of the Camp.

On the north there is a large crescent-shaped ridge of dolerite, formed by the outcrop of a sheet which dips inwards at a comparatively low angle below the mine workings. Taking into account this dip and also reckoning the distance to which the coal will be found altered by the intrusion, it is readily seen that a considerable extent of the mining area will be unproductive. Along the railway at the spot where the Doorn River passes through a narrow gorge the intrusion is very clearly exposed, the strata being faulted. A little higher up, on the plateau, a borehole passed into the dolerite at 150 feet. On the north, Dunn's borehole No. 5 (**6,** '11) penetrated 36 feet of coarse sandstone, and encountered the same intrusion. Galloway's borehole, No. 1, was actually started in the sheet itself, and was abandoned after penetrating over 95 feet of hard jointed dolerite (**13,** 29-34). The east workings in the Dugmore mine have been stopped in coal which shows signs of alteration by heat, and dolerite has been proved in a borehole 400 yards to the north-east of the limit of these workings. Thus the limit of workable coal can be obtained with fair accuracy, due allowance being made for the presence of dolerite dykes, which commonly renders the coal for no small distance on either side unsaleable.

Erosion of Seam.—The Indwe seam is composed of a number of bands of coal and shale, which are constant in character throughout the mining area. The total thickness of the seam

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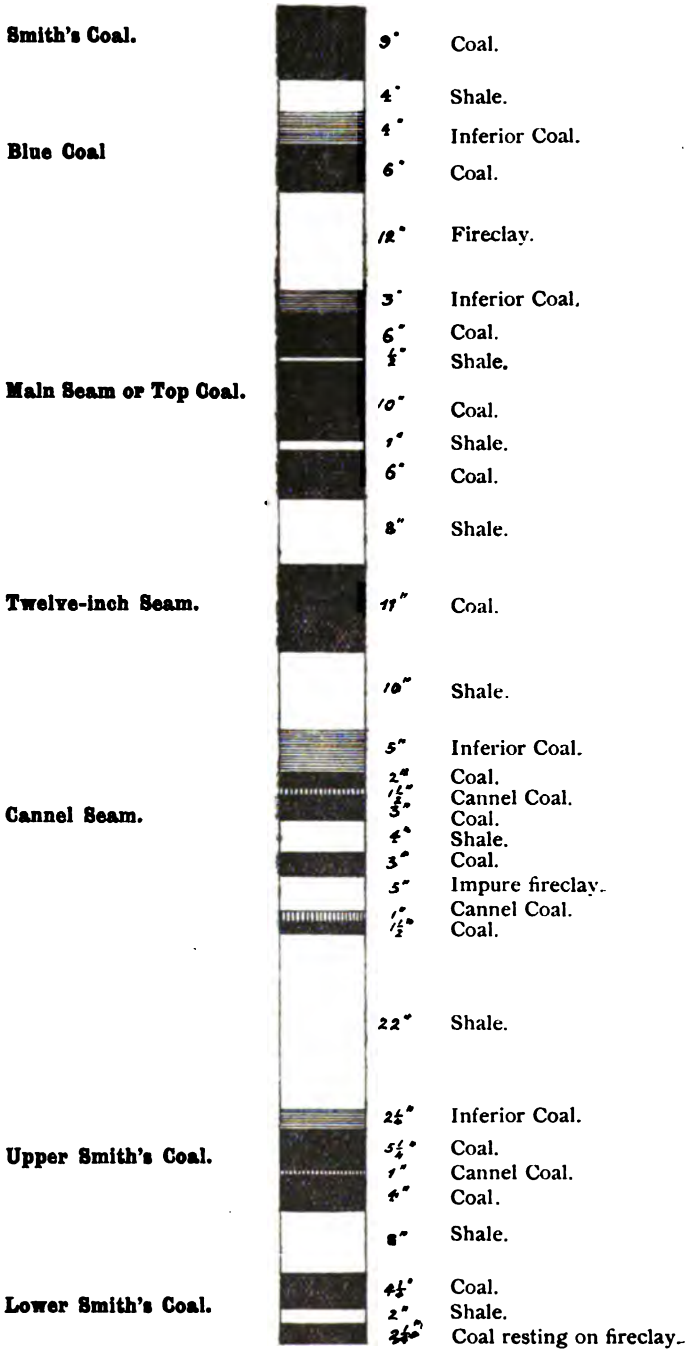

FIG. 1.—Section of Indwe Seam in Green Mine ; thickness, 14 feet.

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varies considerably from point to point, according to the presence or absence of its upper portion. The erosion of the seam was clearly pointed out by Green (7, plate), for he plotted to the same scale a number of sections taken at different points along the outcrop, and thus was enabled to identify the various layers of coal and shale.

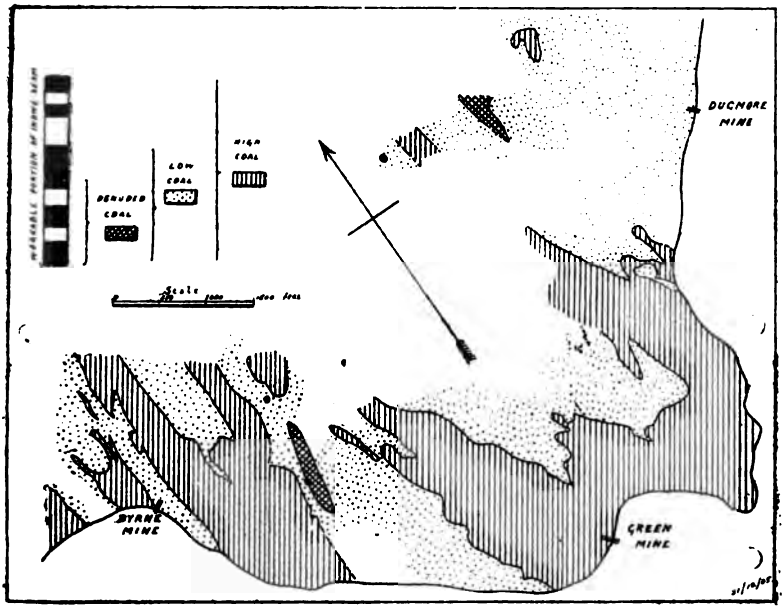

Fig. 2.—Plan of portion of the Indwe Colliery showing areas over which denuded coal is present.

There can be no doubt that these layers extended continuously over the whole of the mining area, and that the upper ones were in certain spots removed by what is termed "contemporaneous erosion," sediment being deposited in the place of the material removed.

This section (Fig. 1), taken from the Green mine, may be looked upon as typical of the coal seam in its entirety; later on certain variations will be pointed out. The thickness of the top (or smith's) coal is in a few places as much as 9 inches, but as the base of the overlying sandstone is wavy and undulating, it is probable that originally its thickness was greater. Perhaps there may even at once time have been higher layers of coal and shale, but as yet they have not been found either in the mine workings or in borings.

The degree of erosion of the seam is most important from a mining point of view, for the two upper coals are of excellent quality, and their absence means a considerable loss.

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In Figure 2, taken from a map made by the Indwe Company, the degree of denudation of the seam is given as far as the workings have extended.

Three degrees of erosion are recognised:—

(1) "*High coal,*" in which a portion or the whole of the two uppermost seams is present. This condition is to be found principally in the Byrne and Green mines, and the average quality of the output is therefore high;

(2) "*Low coal,*" in which erosion has removed a greater or less amount of the main seam. This condition is found throughout almost the whole of the workings of the Dugmore mine; while boring records show that the same condition exists in the unworked area to the north. Little patches of "high coal" will no doubt be present here and there, as, for example, in the small area due north of the Dugmore mine;

(3) "*Denuded coal,*" in which practically the whole of the main seam has disappeared, while even some of the shale above the twelve-inch seam may have been removed. Only two small areas of "denuded coal" have yet been proved in the workings, but as we shall have occasion to point out later, outside the Camp area the Indwe seam is often very much denuded.

From Fig. 2 it will be noticed that these "wash-outs" have a general trend a little to the west of north. Similar "wash-outs" are not uncommon in the British coal-fields—for instance, in the Forest of Dean,† and they must have been caused by streams or currents of water flowing over the seam of coal and shale while they were yet in a soft incoherent state.

The seam at Indwe does not lie horizontally; in addition to the general north-north-easterly dip, which has been given to the beds after their formation, there are also minor undulations, which seem to be an original feature. Apparently the sandstone underlying the seam was not deposited in a perfectly smooth and regular manner, and the thin layers of coal and shale were spread over the undulating surface and perpetuated the irregularities beneath them. At the conclusion of the formation of the seam currents of water carrying gritty sediment swept over the soft carbonaceous deposit. The flow of the water would be directed along the gentle troughs of the surface, and erosion would be most vigorous in the hollows. This is exactly the phenomena that Mr. Colley has noticed, for he informs me that the disappearing of the upper coals can always be predicted by the falling of the level of the lower coals, while with the rising of the level of the latter the upper coals reappear.

Generally, when the dip of the roof is rapid the erosion is deep but the width of the denuded belt narrow, and *vice versa.* Usually, again, where the sandstone in a trough abuts against eroded coal and shale, the former includes peculiar wavy strings

† A. Geikie. Text-book of Geology. Vol. I., p. 639. 1903.

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and lenticles of carbonaceous material, while away from the junction the sandstone is pure. Apparently some of the denuded material has been incorporated with the siliceous sediment. The sandstone just at the junction is often crowded with quartzite pebbles, and permeated to a great extent by iron pyrites; upon oxidation the latter tends to form a strong ferruginous cement. Very often these pebbles occur on the top of the coal, partly embedded in the latter and partly in the sandstone of the roof.

In the north-easterly workings of the Dugmore mine a layer of very evenly bedded and massive blue-black or grey shale, breaking into slabs with smooth polished faces, rests directly upon the slightly denuded main seam. It varies in thickness up to twenty inches, is followed by sandstone, and apparently covers no inconsiderable area. Otherwise the seam is always overlain directly by a thick bed of solid grey sandstone.

Character of Seam.—The various coals which go to form the Indwe seam are of very different thickness and quality.

The *Lower Smith's Coal* is rather impure, but the *Upper Smith's Coal* is of good quality; both coals improve when followed from the Byrne to the Dugmore mine; in the workings of the latter these coals evolve a small amount of firedamp. Owing to the thick bed of overlying shale, the seams cannot be mined economically, and are always left in the workings.

In the *Cannel Seam* the only part worth extracting is the upper portion of from six to seven inches, including a layer of cannel coal from one to two inches thick. Although so thin, this coal forms one of the best portions of the Indwe seam; it is sent out separately from the workings and hand-picked, as the different layers of coal and shale adhere rather firmly.

The *Twelve-inch Seam* is a hard, massive coal, without any partings.

The *Main Seam or Top Coal* is usually rather impure for a few inches at the very top. Then comes from twelve to fifteen inches of hard coal, which, when affected by a dolerite intrusion, exhibits two marked vertical cleavages, and is then known as "square-face." The lowest four inches are very bituminous, and when altered by dolerite, acquire a bright crystalline appearance.

In exceptional cases the seam may reach a thickness of 27 inches; usually it is about 22, and there are nearly always two thin partings of shale or very impure coal.

The *Blue Coal* is bituminous, and very constant in thickness. On the other hand, the fireclay parting between it and the Main Seam is rather variable, its thickness ranging from one to thirty inches, though on an average it is about one foot thick. Molyneux (**5**, 26) records the finding of a quartzite boulder 14 inches long embedded in this fireclay.

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The *Smith's Coal* is good, and bituminous in character. With regard to the quality of the Indwe coal, the only analyses that have apparently been made are by Dr. Hahn, published in Galloway's Report (**9,** 20), and again in Bain (**15,** 26). The three analyses refer respectively to the Smith's (or perhaps the Blue) Coal, the Main Seam, and the Twelve-inch Seam; the analyses, given in Dunn's Report (**3,** 36) are only partial. Far more reliable are tests made with a calorimeter, for it is often impossible to determine the value of a coal from an analysis only.

Innumerable tests have been made by the Railway Department in comparing the relative values of Indwe, Stormberg, and Welsh coals. The principal tests will be found in **8,** 20; **9,** 39 and 50; **10,** 4; **11,** 56, 57; **13,** 44. The latest tests on the Railway give an evaporative power of 5.49 pounds of water with one pound of Indwe coal, as compared with 7.70 and 8.39 pounds of water for two different samples of Welsh coal.

Alteration of Coal.—The coal in the Camp area is often altered by the intrusion of dolerite dykes through the strata. The distance to which this alteration extends, due to the partial or complete loss of the volatile hydrocarbons, is very variable. This may be so even for dykes of similar thicknesses, showing that the molten rock at the instant of injection must have varied considerably in temperature in the different intrusions. The dolerite of the larger dykes is quite fresh and unchanged right up to the contact with the coal, but dykes and sills a few inches wide have usually been converted into "white-trap," which often decomposes, to form a white or yellow clay. Columnar structure is commonly developed in the coke produced by the igneous rock. The objection to this anthracitic coal, or "burnt" coal, as it is commonly termed, is that it develops an intense heat during combustion, which tends to fuse the ash and form clinker.

Strata Above Seam.—The thickness of grey felspathic sandstone overlying the Indwe Seam is about 75 feet, and it then gives place suddenly to a coarse pebbly sandstone, containing the band of ironstone-conglomerate known as the "oyster-bed." It is this thick pebbly sandstone, often false-bedded, that has been called the Indwe sandstone, and that forms such a reliable bench-mark in the Molteno beds. At the base of this sandstone there is found in places in the Camp area a thin impure coal, usually not more than 15 inches thick, known as the "Flying" seam. It is the representative of the Guba Seam, a coal which attains its full section to the west of Indwe.

It is worth noticing that usually when the Indwe Seam is present at any point, the Guba Seam will be absent, and *vice versa.* In only a few localities are both seams developed, and when that is the case, commonly either one or both have deteriorated considerably in thickness and quality.

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Area Without the Camp.—It has already been recorded that a sheet of dolerite underlies the Camp area. The outcrop can be followed along the circumference of a circle about five miles in diameter, in which the town of Indwe is almost at the centre. The strata resting upon this basin-shaped sheet of dolerite have been faulted upwards, the displacement varying from one to two hundred feet.

The intrusion crosses the Indwe River at a point just east of the Dugmore mine, and beyond it the Indwe sandstone is found cropping out on either bank, for a distance of a couple of hundred yards. A borehole almost in the bed of the river struck the Indwe Coal at a depth of eight feet, the seam being considerably denuded.

On the farm Tarka, the Indwe sandstone reappears from beneath the dolerite, in the narrow winding valley along which the road to Cala has been cut. A borehole put down by the Indwe Company near the lower end of the valley penetrated the Indwe Coal at a depth of 107 feet, the seam being denuded to the condition known as " low " coal. The boring was continued in Molteno beds, but abandoned at a depth of 457 feet, after penetrating 21 feet into dolerite. The strata are here on the downthrow side of the fault. Higher up the valley, and to the north, there is exposed a thin, impure coal, which corresponds in horizon to that of the Cala Pass and Newcastle coals. At a slightly higher level, there occurs a bed of hard flinty rock, not more than nine inches thick, and crowded with well-preserved remains of *Thinnfeldia*, *Taeniopteris*, and *Baiera*. It is identical both in characters and geological position with a similar fossiliferous bed, found on the farm Koning's Kroon, in the Elliot* Division.

There is a very large amount of dolerite on Tarka, and, in fact, all along the left bank of the Indwe River, as far north as Roode Hoogte.

In the south-west of Lichfield (lot A), the Indwe sandstone forms a precipice, crowned with dolerite, overlooking the plain of the Indwe River. At a point just behind the homestead, known as the Indwe Farm, a seam of coal was opened out by Mr. Galloway by means of a drive eighteen yards in length. The section given (9, 16) does not exactly correspond to that at the Indwe mine, but there can be no doubt that it must represent the Indwe Seam. The coal is anthracitic, due possibly to the overlying dolerite, but perhaps more probably to a vertical dolerite dyke, striking north and south, and cutting through the coal on the right of the adit. A more unsuitable position for an opening could hardly be found, for this intrusion marks a line of fault, with downthrow of about a hundred feet to the east. The strata dip to the north-north-east at an angle of about two degrees.

* Ann. Rept. Geol. Comm. for 1903, p. 181.

The overlying sheet of dolerite extends some distance to the north-east before it dips below the surface, and it is quite possible that the seam extends in an unaltered condition for a fair distance, perhaps continuously to Tarka and Cradock, but there is always the possibility of unsuspected dolerite intrusions.

A number of boreholes were put down on Lichfield, upon a horizon considerably above that of the coal. In the majority of instances, however, the great sheet of dolerite was encountered.

On the farms Drooge and Vlakte, on the other hand, eleven boreholes were put down by the Indwe Company, and coals proved in most of them. The area is fairly free from dolerite, and slopes gently to the north, the inclination being slightly less than the dip of the strata. Seven of the holes were arranged along a straight line, and the same coal seams struck in all, except in Number 8.

This penetrated dolerite at 130 feet, and as there is a discrepancy between the levels of the coals in the adjacent boreholes Numbers 6 and 9, it is probable that the dolerite marks a line of fault with a moderate downthrow to the north.

The lower seam was met with at from 175 to 215 feet from the surface usually; above it comes from 35 to 45 feet of sandstone, shale, and mudstone, and then the "flying" seam, which is in turn overlain by about 100 feet of grey sandstone.

The "flying" seam is very variable in character, but appears to include one good band of coal, about a foot thick. The lower seam includes two layers of coal, about 11 and 14 inches respectively.

It is only by sinking a shaft that the real thickness and quality of the coal can be determined, and perhaps it may prove possible to work these seams. There is dolerite to the south and west of this area, and thin sheet-like intrusions have penetrated both seams in No. 10, but there appears to be an extent of several square miles over which the coal has been proved, while a considerable portion of the same two farms lying north of the railway has not yet been tested.

There can be no doubt that these coals are on a considerably higher horizon, geologically, than that at the Camp.

In the first place, the Red beds crop out on the face of the ridge to the north, so that the lower seam must lie on a horizon about 350 or 400 feet below the base of that formation. Secondly, the borehole Number 3 reached a depth of 802 feet, all in Molteno beds, the boring being discontinued owing to the jamming of the crown. The 613 feet of beds below the coal seam were principally coarse grey sandstones, with thin bands of mudstone and shale, often coaly and crowded with plant remains. The borehole terminated in coarse grey sandstone.

As the core has not been preserved, it is impossible to say whether the boring is entirely in beds above the Indwe sandstone or not, but I am inclined to the view that the hori...n of the Indwe seam has been penetrated at a depth of about 600

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feet, and that the Indwe coal is not developed in this locality. This great depth is due partly to the cumulative effects of down-throw faults produced by dolerite intrusion, and partly to the increased northerly dip of the strata; on Cradock, the inclination is as much as five degrees.

Turning now to the area north-west of Indwe, we find that along the Doorn River, just beyond the "poort," the strata are faulted down by the dolerite intrusion. The Indwe seam is evidently continuous from the Byrne mine, and has been exposed in several openings on the left bank of the river. The most important of these drives is known as Trennery's, and a section of the seam is given by Galloway (**9**, 18), also an analysis of the coal (p. 13). It is evident that the seam is here denuded to less than two-fifths its full thickness. In a borehole put down by the Indwe Company to the rear of the opening, the seam is less denuded, but only one-third of the main seam has escaped erosion.

Higher up the Doorn River, almost on the northern boundary of Doornkop, the stream is crossed by a dolerite dyke, which faults the Indwe sandstone and coal downwards to the north, a distance of about 50 or 60 feet.

As the dyke is followed across Perseke Plaats, the throw of the fault diminishes. On the east, the dyke extends across Koorn Hoek, and its extension is probably the intrusion seen crossing the "Remaining portion of the Camp," joining up with the dolerite mass on the Indwe River. The strata at a point between the road and the river are much tilted at the contact with the north side of the dyke, so that it is very likely that the throw of the fault is greater here than on the Doorn River. A borehole put down by the Indwe Company to the north of the dyke, close to the railway, reached a depth of 569 feet, but only traces of coal were met with about half-way down. Two dolerite sills were penetrated, and the boring terminated in dolerite.

Here, again, it is difficult to decide whether the Indwe coal horizon has been passed through, or whether it lies at a still greater depth. The surface at the top of the borehole is about 31 feet lower than the opening at the Green mine; from the latter, the seam falls about 200 feet to the dolerite sheet forming the boundary of the camp. This faults down the beds beyond fully 150 feet, perhaps more, after which we find the vertical dyke from Perseke Plaats, which gives a downthrow of probably 100 feet at the least. The strata also dip at a greater rate hereabouts, so that the minimum depth of the horizon of the Indwe seam would probably be not less than 550 feet. It is possible that the seam may have been completely denuded, or else it may have been replaced by dolerite. It is worth noting that on the Doorn River the dolerite dyke occupying the line of fault is seen to give off thin sheets, which penetrate the coal seam on either side of it.

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The prospect of workable coal on Koorn Hoek, Remainder of Camp, Middlecourt, and Stil Fontein is very small. Not only will the Indwe seam, if present, be found at a considerable depth, but there is evidence of great igneous masses intruded into the strata below. From Perseke Plaats, over to Middlecourt, there is a peculiar intrusion of dolerite, which projects at intervals through the strata in dome-shaped masses, but which is evidently continuous below ground.

The borehole Number 4, put down by Dunn at some distance from any visible intrusion (on Middlecourt), entered dolerite at a depth of 162 feet. The igneous rock probably extends underground to the north, for another borehole, almost on the boundary between Jonas' Hoek and Koorn Hoek, penetrated dolerite at 125 feet.

North-eastwards, on Koorn Hoek, Stil Fontein, and Onverwacht, the Molteno beds are hidden by thick grass-covered soil.

On Roode Hoogte, a borehole was put down by North (**4**, 8), just below the base of the Red beds, and an eighteen-inch seam of coal proved at a depth of 80 feet. This is probably one of the highest seams known to occur in the formation.

On Doornkop and Perseke Plaats, a considerable amount of development was carried out, principally under Mr. Galloway's direction. The little plateau north of the railway has been proved by four drives, usually known as " Ferguson's Openings." A large scale plan and a detailed report upon the drives, including results of tests made with the coals, will be found in **11.**

The coal is the Indwe Seam, much denuded, and, as a whole, somewhat inferior in quality to that at the Camp. In some parts of the area as much as half of the main seam still remains, but elsewhere it has wholly disappeared. The seam overlying the two-foot shale band in the sections accompanying the report (**11,** plates 3 and 6) must correspond to the Cannel Seam of the Camp. Actually, it is so mixed with shale that it would not be worth mining. The only coal, therefore, worth extracting will be the two seams below it, aggregating 20 inches.

The dip of the strata is to the north-east, at first gently and then steeper, but a thin dolerite sill (from the Perseke Plaats-Koorn Hoek dyke) has completely replaced the seam in Number 4 drive, and will probably be found in the western workings also.

A borehole on top of the plateau penetrated the Indwe sandstone, and at 35 feet provide thin black shales, which represent the Guba coal horizon (**11,** plate 9).

The strata dip rather rapidly in the east corner of Perseke Plaats, and a borehole (No. 3) put down by Dunn (**6,** 10) has evidently just failed to reach the Indwe seam, though the Guba horizon was marked by a layer of impure coal, fifteen inches thick. A deepening of this hole by a few feet would

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probably prove the Indwe Seam. About half a mile to the north-east (but on the farm Jonas' Hoek), a bore-hole sunk by the Indwe Company reached the Indwe Seam at a depth of 266 feet, the coals below the main seam being alone re-presented.

The strata continue to dip north-eastwards, hence Dunn's No. 2 borehole, 102 feet deep (**6**, 10) did not reach the Indwe horizon. The core, however, showed that the anticlinal sheet of dolerite, which crops out a little to the north-west, dips downwards to the south-east below Perseke Plaats and Jonas' Hoek (see fig. 3). The available area of coal will probably be rather small.

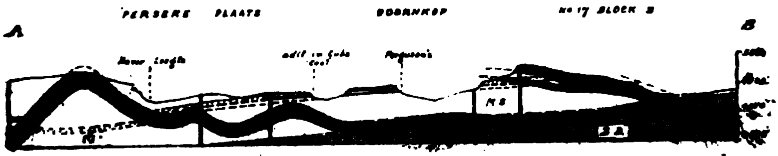

Fig. 3.—Section along line. A B on map, length 6 miles ; M.B., Molteno beds ; B.B., Burghersdorp beds ; intrusive dolerite coloured black.

On Perseke Plaats, almost on the Doornkop boundary, there are two long drives, about 60 yards apart, which expose the Guba coal. Resting upon soft sandstones, there comes a layer of coal, about two feet thick, followed by thin beds of shale and impure coal. This very thick coal at the bottom of the seam is most distinctive of the Guba horizon, and consequently ren-ders it easily distinguishable from the Indwe Seam. The roof consists of coarse grits and ferruginous sandstone, often very pebbly (the Indwe sandstone). The coal is somewhat anthra-citic in character, and dolerite must be present not very far below the seam (see fig. 3). The extent of the seam cannot be very great.

As already noted, there are only about fifteen inches of coal in Dunn's No. 3 borehole, about a mile to the north-east; while beyond the Doorn River, the seam is absent. Even in the oppo-site direction, the coal apparently disappears before the great dolerite mass of Perseke Plaats is reached.

Almost due south however, on Doornkop, the Guba Coal has been opened out just below the Indwe sandstone in an adit known as Hadow's Opening (opening J. of Galloway (**11**, plate 3); see analysis in **9**, 13).

The section shows a basal seam 23 inches thick, overlain by four thin coals, from 3 to 6 inches thick, parted by black shale.

The Indwe sandstone forming the roof is very coarse-grained, and is crowded with ferruginous nodules, often of large size; while pebbles of vein quartz up to one inch in diameter and

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large boulders of quartzite are most abundant. About three feet above the seam the ferruginous nodules are concentrated to form the layer known as the "oyster-bed."

A borehole, put down by the Indwe Company, about 100 yards behind the opening, penetrated this coal at 20 feet, and the Indwe Seam at 112 feet, the two coals being separated by 87 feet of bluish-grey felspathic sandstone. This is one of few places in which both seams are present.

The Indwe Coal is not of very good quality, and the greater portion of the main seam is missing. Boreholes put down further west show that the Guba Coal disappears in that direction; the Indwe seam continues, but in a more denuded condition. Beyond the series of bends on the railway, borings have indicated the underground extension of the Perseke Plaats dolerite sheet (see fig. 3).

The dolerite "anticline," which stretches from Jonas' Hoek southwards, rises in that direction, and on the west end of Doornkop the strata beneath the arch are exposed. One "limb" turns westwards, past Umhlanga Station, and forms the boundary ridge between Wodehouse and Glen Grey for many miles; while the other turns southwards into Macubeni (Glen Grey).

The strata in the basin drained by the Cacadu River are on a horizon above the Indwe Coal; in fact, on No. 6, block 4 (Glen Grey), the Red beds appear beneath the dolerite along the Wodehouse boundary.

North of the intrusion, lower strata are met with, owing to the displacing action of the dolerite, and the Indwe sandstone forms an inlier in the valley of the Haver Leegte.

In the north-eastern corner of Vlakte Fontein, an adit exposes the Guba Coal, and a shaft put down at the same spot reached the Indwe seam, which was too anthracitic to be worth working. Boreholes on Riet Spruit passed into dolerite, and it is evident that the northern limb of the dolerite "anticline" extends below Umhlanga's Location, with a very low dip to the northward.

Along the left bank of the Haver Leegte, the Indwe sandstone forms a cliff, at the foot of which (on Catherine's Post) the Indwe Seam has been exposed in several old openings. The coal appears to be denuded, but at the same time there seems to have been irregularities in deposition, and shales may pass laterally into coal or sandstone. This variability of the seam was also noted by Dunn (**6**, 11).

On Brak Leegte, there are two adits exposing the Guba Seam, but in boreholes to the north and south this coal is absent, and only the Indwe Seam was represented.

A shaft was sunk by a Scotch syndicate to cut the latter, but I was not able to measure the section of the seams. From the information given me by Mr. Botha, the owner of the farm, there

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are three seams, 24 inches, 9 inches, and 8 inches respectively, corresponding evidently to the three lowest seams at Indwe. It is certain that we have here the very much denuded Indwe Seam, but it is possible that a greater thickness of coal and shale may be present underlying other parts of this locality.

Further up the Haver Leegte higher beds of the Molteno series are met with, and they form an escarpment along the face of which the railway has been carried; in the numerous cuttings fine sections are exposed, but no coals appear to be present. Outliers of Red beds are seen towards the north-west and south-west.

Further down the Haver Leegte, the strata dip rapidly to the east and north-east, and the Indwe sandstone is succeeded by higher beds. On Spioen Kop, Dunn put down a borehole (Number 1), a little above the drift on the main road from Dordrecht to Indwe (**6**, 10), but it is evident that the horizon of the coal must be at least 500 feet below this point.

In places along the river bank the "glittering" sandstones have had their component quartz grains cemented by chalcedonic silica. The rock is then very hard, and weathers to a paler tint than the normal sandstone. At the top of the ridge overlooking the drift there is a thin bed of yellow friable sandstone, crowded with pebbles, and becoming in places a conglomerate. The pebbles vary from half an inch up to a foot in length, are very smooth, and consist chiefly of various types of hard quartzites, but grits, hard white slates, and a pebble of quartz-felsite were also seen.

Turning attention now to the area lying south of Indwe, we find a few miles distant from the town three prominent kopjes, overlooking the plain of the Guba River. On their northern sides there is a dolerite sheet, and the summits of the three hills are partially capped with dolerite.

On the easternmost hill, the position of the Indwe Seam is now indicated by small exposures of impure coal and shale, the old opening being hardly visible; while higher up, small weathered fragments of dark shale mark the horizon of the Guba Coal.

Galloway (**9**, T. p. 13) gives the thickness of the coal. The dolerite sheet has altered the strata considerably; the shales are converted to hard black porcellanite, while the coarse Indwe sandstone has been rendered finely prismatic, the columns being as much as four feet in length and about six inches across. The second hill is similar to the first.

About 10 miles south of Indwe there is a long ridge, formed of Molteno beds, stretching eastwards from the head of the Guba River to the Indwe Poort (Trennery's). On one of the highest elevations, which forms the boundary between Nos. 7B, block 3, and 11B, block 2, is situated Holland's mine.

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The Indwe sandstone forms a plateau, diamond-shaped in plan, from which rise two detached dolerite crowned hills. In the easternmost of these elevations there are two drives, one on the north-east and the other on the south-east, exposing a compound seam of coal and shale, which in geological position corresponds to that of the Cala Pass coals. Galloway (**9**, 18) has given a section of the coal which is platy or laminated, and which in places is coked and shiny, owing to thin dolerite sheets given off from a dyke which cuts through the hill. The thick pebbly sandstone some distance above the coal corresponds very probably to the Gubenxa sandstone in the Elliot Division. Below the Indwe sandstone, no coal is found on the north side of the plateau, but on the south-west side, overlooking the Donga Stream, is an adit exposing the Guba Seam. Probably this is the opening referred to by Molyneux (**5**, 25), as the section he gives agrees with that exposed at this locality.

About a mile nearly due north of Holland's mine, there is an outlying mass of Indwe sandstone, which has been rendered finely columnar by a sheet of dolerite cutting obliquely through it.

Guba Valley.—The high ground separating the valleys of the Guba and Cacadu Rivers, from a spot overlooking Lady Frere to as far north as Doornkop, is a great dolerite-capped plateau, which has been deeply trenched by rivers. The intrusion has generally occurred on a horizon just above the Indwe sandstone, but in several places the base of the sheet rises a bit above that level. The feeders of the sheet can often be traced, and their existence underneath the capping of dolerite is a most important factor to be reckoned with in working any of the coals which occur in this area. One of the most important of these feeders is the large inclined sheet, with easterly dip, running from No. 13, block 3, to No. 11A, block 2 (the Donga Mountain), where it changes its direction and turns westwards towards Mount Arthur (Glen Grey).

In the Guba valley coals are, or rather were, exposed at a number of points, for most of the openings seem to have fallen in at some time previous to my visit.

The localities of these openings are indicated on maps accompanying the Reports of Mr. Galloway (**10**) and Mr. Tilney (**8**), while the total thicknesses of the coaly layers, and occasionally an analysis, are given in the first-mentioned paper.

The prospects on the right side of the valley, *e.g.*, Nos. 10C, block 3, 9B, block 3, are not encouraging, owing to the limited width of the ridge. On the latter farm is the opening known as Jacob's mine, which shows a total thickness of 30 inches of good bituminous coal.

On No. 8, block 3, and No. 9A, block 3, there is a considerable area covered by the Indwe sandstone, but no openings have been made to prove the existence of any seam.

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In the middle of the Guba valley there is an isolated narrow ridge of Indwe sandstone, on the east side of which is Murray's Mine.

The coal is bituminous, and the seam, curiously enough, is on the Indwe horizon. All the other openings in the valley are in the Guba Coal, but the latter is absent above Murray's Mine.

On the left side of the Guba valley, towards its upper end, it is very unlikely that bituminous coal will be found. Along the left bank of the river, for a distance of four miles, dolerite is exposed; just a portion of the convex surface of a sheet coming out of the river-bed, and rising gradually to the north-west. It probably extends underground in that direction, and joins up with the overlying sheet crowning the plateau.

On No. 10B, block 3, was the exposure known as Bradfield's Opening; this is the Guba Seam, containing 2 feet 11 inches of coal, which, according to Galloway (9, 13), is a free-burning anthracite. The overlying dolerite is separated from the coal by a very small amount of sandstone, so that this character of the coal is only to be expected.

In the valley to the north, No. 13, block 3, a considerable thickness of strata intervenes, and in the opening known as No. 4 Guba, the coal is of better quality (9, 13). Should the seam be continuous between the two openings, as is very probable, it is likely that this area may be worth working. Almost opposite No. 4 Guba is the adit known as Tilney's opening, the coal of which contains nearly 32% of ash (9, 13).

The seam is probably continuous down the left-hand side of the valley underlying the area on the map marked "Mineral Lease." Towards the head of the narrow kloof, to the west of this, a drive once again exposes the seam overlain by the pebbly Indwe sandstone. At this point the overlying dolerite comes down rather low, and there is also a little feeder in a branch ravine to the west. The seam is evidently continuous towards the north below No. 14, block 3, and is exposed in two important drives, known as Rimmel's Openings, in the valley leading down to the Doorn River.

The following is a section of the seam:—

Sandstone	Forming roof.	
Shale	9	inches.
Coal	7	"
Shale	2	"
Coal	3	"
Impure coal	3	"
Coal	7	"
Shale	1	"
Impure coal	4	"
Coal	25	"
Shale	Floor.	

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There is consequently a series of thin coals above, and a solid seam of coal, just over two feet thick, below. The roof is the coarse Indwe sandstone, with numerous quartzite boulders and ferruginous concretions. A few hundred yards along the hillside, below a small waterfall, the seam crops out naturally; the exposure is known as the Sheba. There is a thin dolerite intrusion, and the coal is slightly anthracitic (**9,** 16). Towards the north end of the valley, the seam has also been proved, but it is very anthracitic; the same is the case on the north-east.

The Indwe coal may or may not be present in the valley, and it may, perhaps, be worth while making one or two openings below Rimmel's to determine this point. A borehole over 300 feet deep was sunk in the valley, but it started at too low a level. The strata proved were grey sandstones, with thin bands of dark shale.

On the hillside, about 150 feet above the coal horizon at Rimmel's Openings, is an outcrop of shales and mudstones and impure laminated coals, just a little below the dolerite. The shales are crowded with plant remains, and the horizon corresponds with that of the Cala Pass coals (*e.g.*, Tarka and Holland's mine).

Cacadu Valley.—In the valley of the Cacadu River, in the ward of Macubeni, the Indwe sandstone crops out again, and in several localities the presence of one or more seams of coal below it have been proved.

In the north part of No. 1, block 4, there is an opening in the Guba seam, showing a 26-inch band of coal, followed by 3 inches of shale, and then by 6 inches of coal; the full section is given by Galloway (**11,** 3, sect. 1). A second opening, with almost identical section, occurs further to the west.

Below the first opening, in a deep channel cut by a small stream, there is an outcrop of the Indwe Seam, which is very much weathered and of poor quality. The same coal is exposed in a drive a little to the west. About 80 feet of fine-grained sandstone parts the two coal horizons

It is most probable that the Guba Seam, overlain by sandstone and dolerite, extends from this point right through to Rimmel's Openings and those on No. 13, block 3. As shown in the section (fig. 4), the dolerite sheet arches upward slightly, and the coal underlying it will be free from any injurious effect.

A most important question, however, is the presence of any dolerite sills underground, but there are apparently only two intrusions of any importance that may encroach on this area. The first is the southern limb of the Perseke Plaats "anticline," which passes through Doornkop and No. 3, block 4, and forms the northern edge of No. 14, block 3, the dip being south-easterly. It then turns westward into No. 2, block 4, and after that southward into No. 8, block 4, where it faults down the Indwe sandstone, a distance of at least 150 feet to the west.

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On No. 1, block 4, it unites with a sheet of dolerite coming up from the east, an intrusion which will pass below either the north-western or the south-western corner of the mineral lease on No. 14, block 3, depending upon whether it runs in a straight line or in a curve. It will also mark a fault with upthrow to the south-east.

In whatever direction it may run, I think that there will be an area of at least one square mile below which the Guba coal will be present in an unaltered condition. To settle this absolutely would require the sinking of a borehole about a mile behind Rimmel's openings. The hole would pass through about 150 feet of dolerite, and reach the coal at not less than 400 feet. A carefully levelled section would be required to determine the depth exactly.

There would be no difficulty in working the coal from Rimmel's openings, for the seam rises gradually towards the south-west, and a railway not many miles in length would join the main line at a point close to Umhlanga Station.

In the east portion of No. 1, block 4, there is an adit, which was opened by Thomas Zwedala, headman of Macubeni; there is so much dolerite round about that the coal will be of no value.

It has been noticed a little further back that on No. 8, block 4, the Indwe sandstone was faulted down by a dolerite sheet. This is repeated by parallel intrusion, and in consequence the sandstone forms low cliffs, fringing the banks of the Cacadu River, a couple of miles above Macubeni Trading Station. Below the Trading Station a great sill crosses the river—an extension of the Zwart Water intrusion—and produces a dislocation of fully 400 feet, with upthrow to the south. Further downstream several inclined sheets repeat the faulting action. When to this is added the northerly dip of the strata, the presence of the Indwe sandstone crowning the Donga Mountain overlooking Lady Frere finds an easy explanation.

FIG 4.—Section along C.D. on map, length nearly 12 miles; M.B., Molteno beds; B.B., Burghersdorp beds; intrusive dolerite coloured black.

Transkei.—On the east side of the Indwe River the Molteno beds form the plateau of the Umtingwevu Mountains in the Division of Xalanga. Burghersdorp beds occur all along the base of the escarpment, which is crowned with the Indwe sandstone and an overlying dolerite sheet. A slight elevation on the southern edge of the plateau, known as Lubisi, has been used as a trigonometrical station, and has an altitude of 5,823 feet above sea level.*

The conical peak, Trighard's Kop, overlooking the village of Southeyville, is a little lower in altitude. The Molteno beds, so far as is yet known, here reach their southernmost limit, but the outcrops on Thaba Mtheku (Glen Grey) and Bongolo Nek (Queenstown) have almost the same latitude.

(ii). *The Area West and South-west of Dordrecht.*

From Dordrecht, Molteno beds, with occasional small outliers of Red beds, stretch southwards to the Glen Grey border. South of Tweefontein a plateau crowned by the Indwe sandstone extends for several miles into Glen Grey.

On the west side, overlooking the plain on which the trading station of Tsembeyi is situated, there is a drive exposing the Indwe Seam. The section of the seam taken by Mr. G. Hall is given by Galloway (**11,** 4). The coal is anthracitic, as can only be expected, for the whole area is underlain by the immense dolerite intrusion which stretches from Macubeni to Zwart Water.

The limited areas of Molteno beds in Zwart Water, Zingutu, Vaalbank, and Qoqodala are practically enveloped in dolerite, and there is very little possibility of any workable seams being found.

In the south-western corner of Wodehouse Molteno beds form an extensive flattish tract of country, bounded on the north by the watershed of the Stormberg and on the south by the dolerite masses of the Andriesberg.

On Middlecourt (Quagga's Fontein), Uyl Hoek, and along the Birds' River there are extensive sheets of dolerite spreading out nearly horizontally, but from Kalkoen Krans westwards to the Queenstown border the country is undulating, grass-covered, and fairly free from intrusions. In many places rounded boulders of quartzite, often of considerable size, strew the surface of the ground, having been weathered out of some of the sandstone beds.

Coal seams crop out at two localities, the first at Halseton Station, and the second about six miles to the south, on the farm Kleine Vley. At the station, about a quarter of a mile towards the west, there are two drives in the side of a flat-topped ridge.

The coal is thin, and as it contains numerous mud films is very impure; at places it is semi-anthracitic. A section is

* Sir D. Gill, Report on the Geodetic Survey of South Africa, Vol. II, p. 237. Cape Town, 1901.

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given by Green (7, 20). Associated with the coal is a considerable amount of fireclay, which may perhaps be of economic value. To the east the horizon can be traced until it terminates against a dolerite intrusion, which has disturbed the strata considerably. To the north-west the coal passes below a little plateau capped with a dolerite sheet, and its nature in this direction has not yet been ascertained.

Towards the south, on Stones Beacon, the same horizon, represented by black shales, mudstones, and fireclay, is found below a little ridge of gritty sandstone. At a point almost in the centre of this farm a borehole was put down to a depth of 413 feet, principally through blue-grey sandstones and shales, but only streaks of coal were discovered.

On the west side of Beaconsfield, the farm adjoining, a second borehole reached a depth of 402 feet, with a similarly negative result.

The second coal locality is a prominent elevation on the farm Kleine Vley, crowned with a bed of coarse pebbly sandstone. Just below this capping is the seam which has been proved in two drives on opposite sides of the hill, and which shows a considerable thickness of coal. The following is a section.—

Shale … … … … … … … … … … …	15	inches.
Coal … … … … … … … … … … …	1½	„
Shale … … … … … … … … … … …	2½	„
Coal (impure at top) … … … …	7	„
Shale … … … … … … … … … … …	5	„
Coal … … … … … … … … … … …	12	„
Shale … … … … … … … … … … …	3	„
Coal … … … … … … … … … … …	18	„

The coal is somewhat anthracitic, this being due to the proximity of a dolerite sill, while the extent of available coal is, unfortunately, very limited. Three analyses of the coal are given in the Report (15, 27).

To the north-east are three flat-topped hills, capped with the same bed of sandstone, and it is possible that the seam will be found immediately below it; the openings hitherto made have all been on too low a horizon. Further east, on Middlecourt and Uyl Hoek, a dolerite sheet has been intruded just below the bed of pebbly sandstone.

It is difficult to know the exact stratigraphical horizon of these two coals; the only place where there is a continuous succession of strata is some distance to the north-west, at Penhoek, where the Red beds form the upper part of the escarpment of the Stormberg. Elsewhere the strata in this corner of Wodehouse are separated from the strata of the neighbouring areas by dolerite intrusions, occupying lines of dislocation. I incline to the view that the Kleine Vley coal lies geologically a little above that at Halseton Station, and that both belong to the upper portion of the Molteno beds.

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Openings have been made on the sides of Saltpetre Berg, a lofty ridge of Molteno beds close to Penhoek Station, but the results have not been encouraging.

(iii). *The Sterkstroom Area.*

South-eastward of Sterkstroom there is a considerable stretch of mountainous country adjoining the Wodehouse boundary. The strata belong to the Molteno beds, and coals have been opened up on several farms, *e.g.*, Klopper's Fontein, Doornboom, and Vaal Krans, but the seams are always thin and of poor quality, while thick slightly-inclined sheets of dolerite are numerous. A section of the seam on Klopper's Fontein has been figured by North. (**4,** 34.)

Immediately to the east of Sterkstroom, not more than a mile from the town, there is an outcrop of the Indwe sandstone. Dolerite always overlies it, and is sometimes also intruded below it or through it. This is the continuation of the Andriesberg intrusion, and extends northwards, crowning the Donker Hoeks Berg with a magnificent palisade of columnar dolerite. In spite of the abundance of dolerite east of Sterkstroom, a very considerable amount of prospecting was carried out, partly by private individuals and partly under the direction of Mr. T. Bain, on behalf of the Government, about fifteen years ago (**13,** 35 *et seq.*). A long drive exposes coal and shale immediately below the Indwe sandstone, but a sheet of fine-grained dolerite from 3 feet 6 inches to 4 feet thick has wedged itself in at the base of the seam, and is exposed along the entire length of the drive. The coal is highly anthracitic, and fragments of coal and shale have been enveloped in the igneous rock, which, at the junction, is often in the condition known as "white trap." On the top of the little plateau two shafts have been sunk, one on either side of the fence separating the farms Jonas Kraal and Hex River, the seam being proved in both cases.

The Sterkstroom Coal is evidently the equivalent of the Guba Seam in the Indwe Area. Owing to the abundance of dolerite, the coal is always more or less anthracited, and all the samples show a high percentage of ash (**13,** 14; **15,** 27).

As the result of his visit in 1890, Mr. Sichel came to the conclusion (**14,** 6) that these properties east of Sterkstroom were, from a mining standpoint, of doubtful value, and with his views I find myself in complete agreement.

A part that does not appear to have yet been prospected is the base of Donker Hoeks Berg and the flat below it, close to the Indwe railway.

About 6 miles due north of Sterkstroom, on the farm Klap Kloof, a seam has been found which looks very promising.

A considerable amount of development has been done on the west side of the valley, and the workings are quite extensive. The seam is about 30 inches thick, with a thin shale parting

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near the top, but the coal, which is laminated, is slightly variable in character. The continuity of the seam to the south has been proved by a borehole. On the east side of the valley the same seam is exposed at a lower altitude, owing to the easterly dip of the beds. There are two shale partings towards the top of the seam, and there will be about 26 inches of coal available.

The seam is of much better quality than that in the western workings, and contains rather thick layers of glossy coal. It is highly bituminous, and yields on burning a friable white ash, without any clinker.

The following are the analyses* of the two coals made by Mr. J. G. Rose, of the Government Analytical Laboratory, from which it will be seen that the proportion of ash is rather low:—

	West workings.	East workings.
Moisture...	4·31	3·83
Volatile hydrocarbons	30·23	25·37
Fixed carbon	46·57	58·03
Ash	18·14	11·57
Sulphur	0·75	1·20

The extension of the seam towards the north has not yet been tested, but about a mile lower down the valley its presence has been proved by boring. If continuous, the coal will pass with a gentle easterly dip below the lofty escarpment forming the edge of the Molteno Division (on the farm Noitgedacht), beneath which the strata become horizontal, and then rise slowly towards the east. This area is remarkably free from dolerite, the only intrusions being a few narrow and well-defined vertical dykes.

On the west of the valley the available area of coal will probably not be very great, for in that direction occur the great dolerite sills of Bushman's Hoek. The roof above the coal consists of a variable thickness of fireclay, shales, and mudstones, varying in colour from blue to buff and pink. The thickness of fireclay ranges from 10 to 30 feet. Above these soft beds comes a coarse sandstone, which is often very ferruginous and pebbly.

The Klap Kloof coal is apparently just above the Indwe sandstone, the outcrop of the latter crossing Donker Hoek, but being quite inconspicuous.

On Klip Kraal there is a small elevation just east of the homestead, in which the Indwe seam is represented by an outcrop of shale and very impure coal, crowded with remains of *Thinnfeldia*, *Phoenicopsis*, and *Baiera*. The strata are in contact with dolerite on the north-east, and also very probably on the west, but the boundaries of the intrusions are difficult to trace across this part of the district.

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* For these and for information regarding the bore-holes, I am indebted to Mr. J. W. de Kock, M.L.A.

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The farms Klip Kraal, Kraal Dooms, and the Sterkstroom Commonage are formed of strata below the Indwe sandstone, and it is very improbable that seams of any value will be found on them.

On the north-east side of Bushman's Hoek there is a lofty ridge, formed of Molteno beds, and having the continuity of the strata frequently broken by thick dolerite sheets rising out of the valley towards the east.

North-east of the homestead and about 300 feet above it in altitude, is the opening of the Bushman's Hoek mine, immediately below a thick, massive stratum of pebbly sandstone. A considerable amount of labour was spent in the development of the property, and the workings are of no small extent, but the mine has been closed down for many years.

A description of the mine is given by North (**4**, 33), accompanied by a plan of the workings and two sections of the seam. The lowest layer of coal in the seam, about two feet thick, is of very inferior quality. The section is identical with that of the Guba Coal, and like it, is directly overlain by a sandstone resembling the Indwe sandstone.

Although it is at a higher altitude than the coals on both Klap Kloof and Klip Kraal, it is in both cases separated from them by dolerite sheets, and is, I think, on a *lower* geological horizon than the former, *e.g.*, it is on that of the Guba Coal.

In the Bushman's Hoek valley itself and towards the east there is a great sheet of dolerite, by which the strata have been much displaced. Thus on Prospect Peak, in the eastern corner of Bushman's Hoek, the Indwe sandstone has an altitude of about 5,600 feet above sea level, that of the Bushman's Hoek mine is 5,100, while the coal at Sterkstroom has an altitude of 4,550. There is only a slight south-easterly dip of the strata, so that these large differences in level are almost entirely due to the effects of dolerite intrusions. The geology of this part of the country is rather complex, and an examination of those portions of the Molteno Division adjoining will have to be made before the various outcrops of coal can be ascribed to their correct geological horizons.

Below the level of the Indwe sandstone on Prospect Peak are several thin coals, which have been described by Dunn (**3**, 21), North (**4**, 33), and Molyneux (**5**, 34). By all these observers these coals have been regarded as overlying that at the Bushman's Hoek mine, but I have just pointed out that there is a drop of 500 feet between the two spots, owing to faulting.

The uppermost seam is evidently the equivalent of that at the Bushman's Hoek mine (*i.e.*, the Guba Coal). The second, 75 feet below it, must represent the Indwe Seam.

The lowest is 300 feet beneath the Indwe sandstone, and very irregular in character. This coal has also been proved on the flat between this and Sterkstroom in a well along the railway; it is evidently the lowest seam occurring in the Molteno beds.

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For making a study of the nature of the deposits forming the Molteno beds no better locality could be found than the slopes of Prospect Peak, up which the railway ascends from Bushman's Hoek to Cyfergat.

The deep cuttings expose fine-grained, often highly false-bedded, felspathic sandstones in layers of considerable thickness. The irregular bedding of the deposits is also finely shown by the lenticular and wavy intercalations of shale and mudstone, while instances of contemporaneous erosion and local unconformity are numerous. The thickness of strata intervening between the Indwe sandstone and the top of the Burghersdorp beds is here fully 500 feet.

(IV). The Red Beds and Cave Sandstone.

These two formations occupy only a very small portion of the area surveyed, and then only on some of the higher peaks and ridges. The rocks are well exposed, to the north of Indwe, on the ridge forming the watershed between the Doorn and the Waschbank Rivers.

The Red beds are practically the same in character as in the area to the north,* but the formation is of greater thickness. The junction of these two formations is not well defined, as there are a number of thick white sandstones towards the top of the Red beds. Commonly, however, there is a bed of purple mudstone, with abundant pale, irregular quartzitic concretions, which may be taken to mark the summit of the Red beds.

The Cave sandstone is, as usual, very soft and friable, often weathering into a porous mass, with numerous minute cavities; sometimes the rock contains thin layers of mudstone, and occasionally clay-pellet conglomerate.

On the high peak on Koorn Hoek and on the ridge overlooking Jonas' Hoek the Cave sandstone forms a capping fully 500 feet thick, which is much greater than either to the north-east or north-west. No traces of the Volcanic beds were met with on the ridges west of the Waschbank Peak.

Towards Dordrecht the mountains reach a lesser altitude, while at the same time the strata rise, so that west of Brak Leegte the Red beds only occur as detached and irregular outliers.

The monoclinal fold described in the last Annual Report (p. 84) as running from Moordenaar's Hoek to the corner of Naauwpoort was followed several miles further to the southward. On Limoen Kloof, where the main road from Dordrecht to Queenstown crosses the axis of the monocline, the strata dip

* Ann. Rept. Geol. Comm. for 1904, p. 91.

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to the west-south-west (down the valley) at an angle of fifteen degrees, and the base of the Red beds is brought down about 600 feet before the strata become horizontal again.

Owing to this fold, Red beds build up the high ground on Willow Park, while north of Koups Leegte Station they form a lofty peak, known as Wolve Kop, situated on the watershed of the Colony.

From this point to Penhoek the junction with the Molteno beds is obscured by vast intrusions of dolerite. To the north the Red beds form somewhat flattish ground, with occasional ridges or flat-topped hills, and drained by tributaries of the Holle Spruit. This plateau is at an altitude of close upon 6,000 feet above sea level, and extends westwards into the Molteno Division.

North-westward of Sterkstroom, on the southern edge of this plateau, here known as the Bamboes' Mountains, there occur several small outliers of Red beds.

(V). The Volcanic Necks.

In the last Annual Report there were described from the Wodehouse Division thirteen volcanic pipes, from which the Stormberg lavas and tuffs had been ejected.

The fourteenth neck occurs on Catherine's Post, between Dordrecht and Indwe, and though the contacts with the Molteno beds are not seen, it must be about 250 yards long and about half that across.

The material plugging the neck is the usual cream-coloured sandy material, in places brownish and silicified; on the northern side it passes into a typical pale-blue tuff, full of small fragments of sandstone and shale. No inclusions of lava were noted. The pipe is cut through parallel to its longer axis by a dolerite dyke fifteen yards in width, which trends about west-north-west, and forms a prominent ridge. The tuff has been altered to white quartzite at the junction; the contacts with the intrusion show slickensides, and occasionally there is a deposit of white vein-quartz.

The fifteenth pipe, a similar tuff neck, lies almost due south of Dordrecht, on the boundary between the farms Limoen Kloof and Leeuwe Kloof.

A most curious complex of igneous and sedimentary rocks occurs on the farm Stafelberg's Vley, a few miles north-west of Bird's River Siding, and appears to mark a centre of volcanic activity.

Here are vast hills of dolerite rising to a height of over 1,500 feet above the area to the south. A small stream has cut deeply into this peculiar complex, and laid bare the interior of the mass (see fig. 5). On the south-western side the dolerite is seen dipping steeply downwards, the sandstone and shales on

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the exterior of the dome being almost horizontal, and in the interior having an inclination of about 45 degrees.

Dolerite hills hem in the little valley, and everywhere the dip of the intrusions is seen to be away from the centre.

Large areas of sedimentary rocks occur in a tilted position, and basic intrusions have been injected along and across their bedding planes. These strips of sediments dip away from the central point in a fairly regular manner, but they belong to different geological horizons. For instance, on the north-east there are massive gritty and pebbly sandstones, evidently belonging to the Molteno beds; on the west occur sandstones, with thin purple and blue shales, while on the south is a great mass of Cave sandstone fully 350 feet in thickness, with a dip to the south-east.

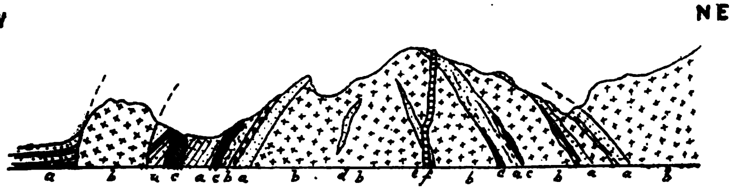

FIG. 5.—Section across complex on Stafelberg's Vley. *a*, Sandstone and shales; *b*, Karoo dolerite; *c*, intrusions earlier than *b*; *d*, hornstone; *e*, cordierite glass; *f*, intrusion later than *b*. Length of section about $\frac{3}{4}$ of a mile.

Abutting against the Cave sandstone is a mass of greenish agglomerate, with fragments of shale, sandstone, quartzite, and occasionally decomposed lava; sometimes there are patches of agglomerate in the sandstone itself.

On the west and north-west there are certain dolerite masses both sheets and bosses, which are traversed by numerous parallel joints, so that the rock very much resembles a ferruginous slate. These intrusions are for several reasons probably earlier than the Karroo dolerite, and are associated with dykes and patches of agglomerate. A thin section (1329) shows a finely porphyritic basalt, very rich in olivine, the latter being now almost completely changed to serpentine.

It is very probable that on Stafelberg's Vley we have an old volcanic centre, of Stormberg age, which was invaded at some later period by vast masses of Karroo dolerite, the sedimentary rocks being much tilted, dislocated, and portions highly metamorphosed. The finer-grained material is altered to hornstone, but some has been completely fused, and has become a cordierite glass.

The thin section (1330) shows an almost colourless, glassy base, crowded with minute cordierite crystals, which sometimes show the characteristic interpenetration trilling, and which are very usually grouped together in clusters. The slide is crowded with minute needles of some indeterminable brown mineral.

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A later dolerite dyke cuts through the whole complex in a north-west-south-east direction (see p. 139).

(VI). THE DOLERITES.

In this area the dolerites are on a more extensive scale, and differ somewhat in habit from the intrusions in the districts both to the north and east. There is a great tendency for a single intrusion to form a highly undulating sheet, which, on being denuded, gives rise in consequence to annular outcrops or to pseudo-laccolitic masses. Of such the Glen Grey sheet is an excellent example.

Some of the dykes apparently are a little later in age than the general period of intrusion, and consequently cut the earlier dolerites. Such intrusions are usually also basic in constitution, but narrow and more acid dykes and veins are frequently present, thus recalling characters in the dolerites of Komgha and Kentani, further to the south-east.

Sheets.—A peculiar feature, very well marked, and noticed in the area east of the Indwe River also, is the tendency for sheets of dolerite to immediately overlie the Indwe sandstone. In this way we find that the sandstone in most cases forms the scarped edges of extensive dolerite plateaux; for example, between Indwe and Lady Frere, around Cala, and in the Umtingwevu Mountains.

It is difficult to see exactly why the intrusion should take place along this rather than on any other horizon. In many places the Indwe sandstone is underlain by either the Guba or Indwe Coal, which should form a plane of weakness, and which consequently we should expect the intrusion to follow. Above the sandstone, too, we often find the equivalents of the Cala Pass Coals, but, as a rule, the level of intrusion is a little lower down.

Perhaps an explanation may be sought for in the fact that the Indwe sandstone is coarse and porous in character, and therefore likely to have contained a fair amount of moisture. This would be converted into steam by the molten dolerite, and would act as an elastic wedge in advance of it, thus determining the precise horizon of intrusion, which might to a considerable extent be independent of the cohesion of the rock.

Reference has already (p. 117) been made to the "anticlinal" sheet of dolerite on Perseke Plaats and Doornkop near Indwe, and there are a few other examples of intrusions having a similar habit.

The most unique intrusion though is an extension of the Perseke Plaats "anticline." Close to the coal-openings on the latter farm the sheet forms a dome-like mass, which, judging from the habit of similar masses, is probably a curved sheet or pseudo-laccolite. It extends underground to the Doorn River,

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where it forms a peculiar boss, on which the north-easterly beacon of Doornkop is placed. The rock pitches below ground quite suddenly, but reappears almost immediately to the east (on the farm Koornhoek).

The convex upper surface of the intrusion is visible below an escarpment of pebbly sandstones, and the dolerite must extend underground towards the north, for it has been struck in boreholes in that direction. Eastwards no dolerite is seen again until the ridge on Middlecourt is reached.

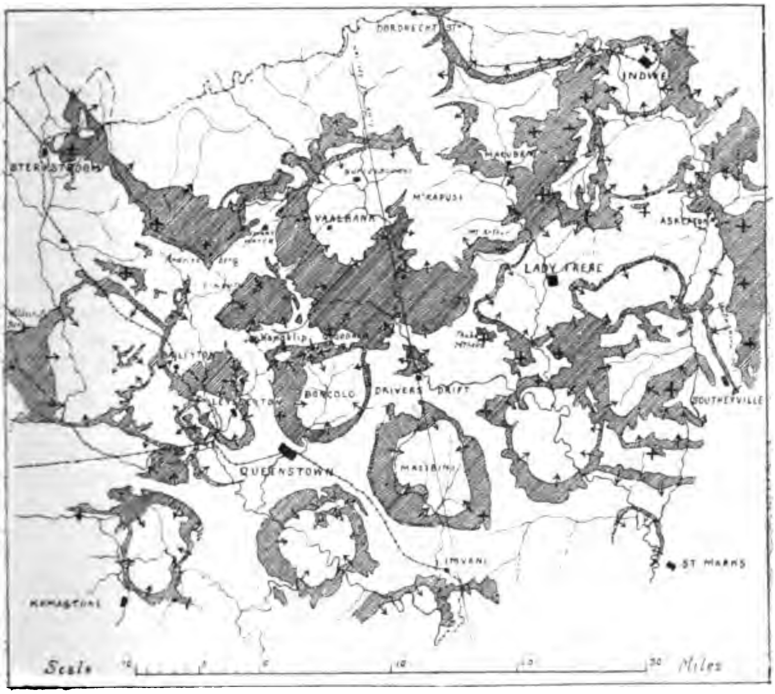

FIG. 6.—Showing the undulations of the Glen Grey dolerite sheet. The arrows indicate the direction of dip of the sheet, the crosses the places where it is horizontal.

The intrusion rises abruptly from the plain to a height of 500 feet, and in habit exactly resembles an anticline or "whale-back" of sedimentary rocks. In all directions the dolerite dips at a high angle below Molteno sandstones, which at the contacts are inclined away at angles of from 5 to 10 degrees; the dolerite was met with to the west in Dunn's No. 4 borehole. The intrusion is not a boss or solid mass of dolerite, for the crest of the ridge is denuded sufficiently to expose sandstones which form the core of the elevation.

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It is evident that there is a single intrusion, a highly irregular sheet, extending from Middlecourt to Perseke Plaats, and only now and then projecting through the sedimentary rocks.

The dolerite on Middlecourt is of the coarse ophitic type common in this area, but there are fine-grained types, giving the rock a well banded appearance, while in places there are brecciated masses.

A thin section (1319) of one of the latter shows an extremely fine-grained rock, with porphyritic crystals of plagioclase felspar and augite surrounding angular fragments of medium-grained ophitic dolerite. The junction between the two varieties is remarkably clear and sharp.

In Glen Grey and Queenstown the Glen Grey sheet, as we may call it, covers a very large extent of country, forming through irregular denudation domes and basins, often of no small diameter. In the east and north the regularity of the intrusion is broken by numerous splits and offshoots from the main mass, while towards the west the sheet is now discontinuous, owing to extensive denudation.

In fig. 6 the ramifications of this sheet are indicated, the arrows showing the directions of dip of the dolerite intrusion; a section through the same area is given in fig. 7. A brief description of the Bongolo valley, just north-east of Queenstown, will serve as a type of one of these basin-shaped hollows. This valley is about 8 miles in diameter—about the average size for one of these basins—and is hemmed in by a nearly circular ridge of dolerite. The drainage passes through a narrow gap in the south side of the ring, and an impounding reservoir is in course of construction here for the water-supply of Queenstown.

From the outside the Bongolo valley appears as a ridge from 600 to 1,500 feet in height of nearly horizontal sandstones and shales, crowned by a steep palisade of rudely columnar dolerite. In the interior the rim of the basin is produced by a slope of dolerite, with an inclination of from 15 to 45 degrees, the igneous rock dipping below the centre of the basin, which is occupied by sandstones and shales. The general appearance of one of these basins is very strikingly like that of a recent volcanic crater.

The dip slopes of dolerite are smooth and shiny, and in many places denudation has only recently removed the overlying sediments, and a thin covering of highly metamorphosed rock may still adhere to the upper surface of the sheet. It is these smooth dip slopes which led Stow† to advance the theory of a recent glaciation in the Eastern Province; his "moraines," too, consist of spheroidally weathered sheets of dolerite, *e.g.*, Bongolo Nek, Bolotwa, and Komani valley. On the north side of the Bongolo the dolerite rises rapidly, and then spreads out horizontally on the ridge overlooking the Qoqodala Mission Station; from this point it dips rapidly north-eastwards to form a similar

† l. p. 534 et seq.

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basin in the Qoqodala valley. On the north-west side of the Bongolo there are two subsidiary basins in the sheet; in one of these the floor is formed of sedimentary material, but in the second the latter has been entirely removed.

The sheet then rises rapidly towards the north-west, and the finely-columnar mass crowning the lofty Hangklip is without doubt the central portion of the dome round which the basins of the Bongolo, Lesseyton, the Zingutu, and Qoqodala are grouped. Of all the basins in this area, perhaps, the most regular is the one which occurs due south of Queenstown, and which is traversed by the Zwart Kei and Klaas Smits Rivers; it shows, too, a subsidiary basin on its northern side. The basin of the Macibini due north of Imvani, is another fine example; all the drainage from this area passes through a "poort" in its southern side.

Driver's Drift is situated almost at the centre of the consequent dome, but the strata have been intensely denuded, and the White Kei River has laid bare the crown of a second dome, probably concentric with the first, and fully 2,000 feet below

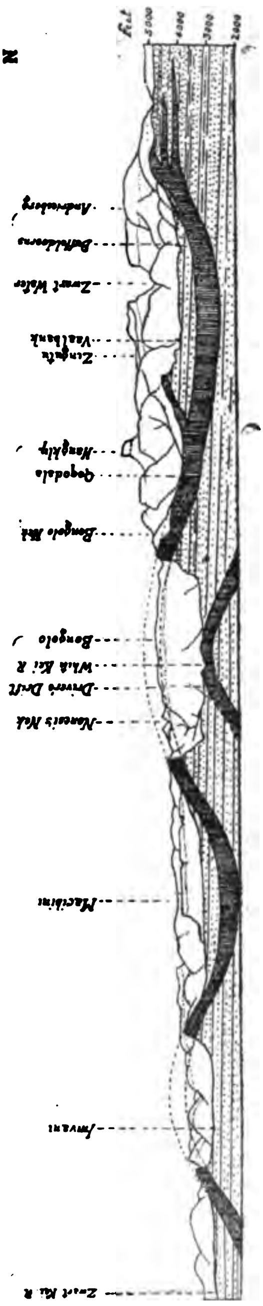

FIG. 7.—Section from Imvani to Buffeldoorns (looking west) showing the undulations of the Glen Grey dolerite sheet. Length of section 45 miles. This, taken from south to north, shows the Imvani dome and in the distance the exterior of the basin traversed by the Zwart Kei and Klaas Smit's Rivers. Then comes the Macibini Basin, the denuded dome at Driver's Drift, and the exterior of the Bongolo Basin. Further north comes the Qoqodala and Buffeldoorns Basins, with the dolerite crowned masses of Hangklip, the Zingutu and Andriesberg in the distance. The foot hills at Vaalbank and Buffeldoorns are formed by the Glen Grey sheet rising out of the valley and capping the hills beyond. The gap at Zwart Water represents a denuded dome.

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the estimated position of the latter. Towards the east a remnant of the dome in the Glen Grey sheet is seen in the remarkable dolerite-capped Thaba Mtheku.

The Qoqodala basin is floored partly with dolerite and partly with sedimentary material. The great areas occupied by hornstone and quartzite indicate the close proximity underground of the dolerite. The Qoqodala basin is only a subordinate to the great basin of Vaalbank, Buffeldoorns, Tsembeyi, and M'Kapusi, which is over 15 miles long and nearly as much across.

It is drained by two separate river systems, that of the White Kei in the west and that of the Cacadu River in the east.

On the north side the dolerite ring is not complete by about a mile; the gap is due to the splitting up of the intrusion, and the dipping of the off-shoots below the strata which form the high ground of the southern portion of Wodehouse.

There are several important points in connection with these intrusions. The first is that the top of any dome appearing in the midst of sandstone and shales will lead one to imagine the existence of a laccolite, and its real character would not be suspected unless denudation had partly revealed the interior. These pseudo-laccolites, as we may call them, will not affect the inclination of the adjoining strata to any appreciable extent, and this will explain why the sedimentary rocks maintain their normal dip up to the very contact with dolerite masses, which rise sometimes to 1,500 feet in height, and which are to all appearance laccolites having that thickness. The fact of their being hollow sheet-like intrusions will explain much.

The Glen Grey sheet varies in thickness from 200 to 500 feet, as a rule; but there is very commonly a swelling at the top of a dome, and though no section is laid bare through the bottom of a basin, it is very probable that a similar thickening exists there.

As examples of such thickenings may be mentioned the Andriesberg, in the south-west corner of Wodehouse, and the Wildschuts Berg, on the western border of Queenstown, which are crowned with horizontal masses of dolerite, about 1,500 feet and 2,000 feet thick respectively.

The inclined portions of the sheet are, as a rule, much thinner than the horizontal portions, and this is more pronounced as the inclination increases.

This can be well illustrated by simply cutting a wavy line through a piece of cardboard, and drawing the two portions a short distance apart in a vertical direction. The cardboard will represent the sedimentary rocks, and the wavy opening the space occupied by dolerite.

The variation in level of the Glen Grey sheet is often very considerable, even within a very short distance; for example, between Hangklip and Lesseyton, a distance of not more than 7 miles, the drop is over 3,500 feet.

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The intrusion has always produced dislocation of the sedimentary rocks, and the amount of displacement is often considerable, the beds above the dolerite being raised relatively to those below. Some of these faults, namely, those which are met with in the Indwe area, have already been referred to.

Besides the Glen Grey sheet, there are numerous other sheet-like intrusions, some great and others small, many of which are only offshoots from it. For example, we have the tracts just south-west of Dordrecht, between Dordrecht and Sterkstroom, and to the north-west of the latter place.

Petrography.—Throughout the whole of this area the dolerite is the usual typical ophitic rock, rather coarse-grained in character; this is especially the case with the Glen Grey sheet.

In several places there are deviations from the normal type.

In Bushman's Hoek, at the old homestead, is a great mass of light grey dolerite, in which the ferro-magnesian mineral is in the form of long needle-shaped crystals. A thin section (1,336) shows these to be augites, which are now altered to yellowish serpentine; the rest of the rock consists of plagioclase felspars, with a fair amount of interstitial quartz.

At the Tarka border, on the main road from Sterkstroom to Tarkastad, there is a somewhat different rock. The section (1,334) shows an intimate intergrowth of pale brownish augite and a pale green hornblende, large crystals of plagioclase felspar, much magnetite, and a very large amount of quartz, usually forming a micrographic intergrowth with felspar. An acid vein in this sheet (1,335) shows almost entirely quartz and micropegmatite; felspar into which quartz does not penetrate is quite rare. The rock may be termed a granophyre.

These acid veins are by no means infrequent; one, six inches wide, from a point four miles south of Lehman's Drift Siding, is composed chiefly of granulitic quartz and felspar (1,326). Another from Fincham's Nek, six miles south of Queenstown, contains dark green hornblende, and is very rich in micropegmatite (1,327).

Dykes.—The second class of intrusions, namely dykes, are extremely abundant. Though usually from 12 to 30 feet wide, they often run in straight lines for very many miles. As in the adjoining areas, so also here, the course of these dykes is most commonly either north-east or north-west.

In the coal-workings at Indwe there are several peculiar dykes. In the Byrne mine there is an intrusion which ends bluntly in the middle of the seam, the coals and shales being arched upwards to a small extent over the termination of the dyke. The dolerite is fine grained, and has a dark glassy base (1,315).

In the Dugmore mine there is an eighteen-inch dyke, with a termination that is semicircular in transverse section. It strikes east and west, and pitches rapidly eastwards, so that in a short

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distance it disappears below the floor of the workings. The shale and coal overlying the top of the dyke are arched upwards for a short distance.

Close to it there is another remarkable dyke, which is now in the condition known as "white trap." It is seen only in the roof, and can be traced for a short distance in the workings by the downward bulge it has produced.

A small outcrop of acid rock was met with in the ward of Lante in Glen Grey, which both in character and mode of occurrence differs from the usual type of intrusion.

The road to Bengu winds round a spur, crowned with a massive sandstone bed, which forms a rude horseshoe, the depression in the centre being occupied by friable sandstone and mudstone and by the igneous rock. The latter forms a small isolated patch, not more than 40 feet across, is light grey in colour and vesicular, and in places contains fragments of dolerite.

In section (1,328) it shows a fine-grained mass of quartz and felspar, with patches of chlorite, and crystals of epidote and magnetite. The vesicles are not sharply defined from the ground mass, and are filled with quartz, aggregates of chlorite with rudely hexagonal outlines, and large clear crystals of yellowish epidote.

The rock seems to form a plug-like mass.

Later Intrusions.—In a few places a second and later intrusion has followed the Karroo dolerite, either along the same path or along an entirely new fracture. In the former case we get a composite sill or dyke, and the best example of this is one that occurs on the railway between Sterkstroom and Penhoek (on the farm Gretna).

The earlier intrusion is a thick dolerite sheet—an extension of the Andriesberg mass—which is decomposed to a coarse friable sand and is quarried for ballast. The sheet is at first horizontal, and then dips eastwards at an angle of about 25 degrees. The second intrusion has taken place between the upper surface of the older one and the overlying sedimentary material, and is dark, solid, and fine-grained. For some distance these two intrusions can be distinguished in the field by their differences in weathering.

Close to Birds' River Siding there is a similar double intrusion; the later dolerite is hard, weathers red-brown in colour, and caps several flat-topped kopjes, formed of decomposed coarse-grained dolerite. In one of these, a little west of the Siding, a tongue fro mthe overlying sheet penetrates irregularly into the lower intrusion.

Outside this area similar composite sills have also been noticed; for example one occurs along the railway about a mile south of Stormberg Junction.

The second class of later intrusives forms dykes cutting through the earlier dolerites.

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South of Indwe, between the westernmost and the middle kopje, is such a one, about 20 feet in width, cutting through a thick sheet of coarse ophitic dolerite. The dyke is a beautifully porphyritic rock, with a very fine cryptocrystalline groundmass (1,317), shows a chilled selvage, and is rudely columnar, with the columns arranged normally to the sides. The best example, however, is met with at Birds' River Siding. On Stafelbergs Vley it cuts through the complex of igneous and sedimentary material (described elsewhere in this report), and forms a wall of horizontal prisms, which projects above the surface of the earlier intrusion, to a height of twelve feet in places. A thin section (1,332) shows a felted aggregate of felspar and augite prisms, set in a deep brown glassy base.

It was only followed to the summit of the Stormberg watershed, but from Dunn's Map it extends for many miles further to the north-west. In the opposite direction, it can be traced down the Birds' River, and cuts through the dolerite masses of the Glen Grey border. It is very probable that the prominent dyke which runs from Tsembeyi through to the ward of Bengu is the extension of this intrusion.

A nearly parallel intrusion, usually less than a mile distant, accompanies it on its north-west side, starting from Tsembeyi, and crossing into the Transkei at Southeyville.

Both of these dykes pass through the town of Lady Frere, while to the north-west, they cut right through the towering mass of Mount Arthur. This mountain is capped with a thick dolerite sheet, and the course of these intrusive dykes is marked by deep clefts. A similar feature is noticeable in the dolerite cap on the mountain Thaba Mtheku.

VII. Superficial Deposits.

Over most of this area the soil is thin, but in some of the basins and along many of the rivers there are flats of very fertile soil. A very good example is a well-cultivated flat not many miles east of Lady Frere, also the stretch of ground between Bolotwa and St. Marks. The mudstones of the Burghersdorp beds readily crumble away, and form a stiff soil, which is more fertile than that derived from the disintegration of the Molteno beds. The complete decomposition of many of the dolerite dykes and sheets as a rule increases the fertility.

In the west and north-west portions of Queenstown and in Tarka there are large tracts of nearly flat country, over which there is a deposit of calcareous tufa, extremely hard and usually covered with a thin sandy soil. This deposit is often from four to six feet in depth, and may pass into a conglomerate by the cementing of waterworn boulders of sandstone, flinty shale, and dolerite with a white limestone, which is often of remarkable purity.

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Bones have been found in these recent deposits, but never those of any extinct forms.

Ironstone gravels occur in places, but never form beds of any depth or lateral extent.

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GEOLOGICAL SURVEY

OF

PARTS OF HAY AND PRIESKA, WITH SOME NOTES ON HERBERT AND BARKLY WEST.

BY

A. W. ROGERS.

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CONTENTS.

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GEOLOGICAL SURVEY OF PARTS OF HAY AND PRIESKA, WITH SOME NOTES ON HERBERT AND BARKLY WEST.

By A. W. Rogers.

Introduction.

The area described in this report lies between the Vaal River on the east and the Kalahari on the west; it is limited by the Vryburg southern boundary on the north and the Orange River on the south, and a small area near Omdraai Vley, in Prieska, is also mentioned.

The country between the Vaal River and the western side of the Kaap Plateau was only traversed once, so it is not dealt with at length.

The Vaal River runs in a south-westerly direction to join the Orange River through a somewhat featureless country, which rises gradually from the right bank to the foot of the Campbell Rand or Kaap Plateau. The escarpment which limits this plateau on the east trends at first north-eastwards from the Orange River, and then north-north-east for about 160 miles; it comes to an end near Vryburg, where the boundary of the limestone and dolomite which form the plateau turns westwards. In the area we are now concerned with the highest part of the plateau lies about 600 feet above the lower ground to the east, though the precipitous escarpment is not more than half that height.

The surface of the plateau slopes gradually towards the western limit formed by the Asbestos Mountains, at the foot of which the village of Griqua Town is situated. The so-called Asbestos Mountains are really a range of rather flat-topped hills, cut into by the valleys of many tributaries of the Orange River, some of which rise in the country behind and cut through the range. These hills rarely exceed 700 feet in height above the Orange River at Prieska. The trend of the Asbestos range is parallel to the Campbell escarpment, and the range is about twenty-five miles distant from the latter.

West of these hills there is a tract of hilly country, about thirty-six miles wide, bounded on the west by the Langebergen. This hilly country becomes more and more sandy towards the Langeberg, which rises to a height of about 1,600 feet above the valley to the east. From the top of the Langeberg, one looks

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westwards far across the Kalahari, the general sandy surface of which is broken by the serrated ranges of Scheurberg and Inkruip. The Langebergen themselves have remarkably rounded summits, without any sharp peaks, though in the subordinate range east of Andries Fontein, where thick belts of shale are intercalated with the quartzites, the latter make a few prominent ridges.

The average trend of the Langebergen is north-north-east, though they are really an arc with a radius of about 105 miles round a centre some 30 miles north-north-west of Upington. Owing to this arc arrangement, the extreme southern end of the range (Ezel Rand, in Prieska) has a north-easterly strike; the middle portion trends north-north-east,and the northern part more nearly north and south.

The formations that appear at the surface in this district are:—

Recent and Superficial Deposits.—Sands, gravels, alluvium, calcareous tufa.

(Great unconformity.)

Dwyka Series.—Glacial boulder beds, gravels and shales.

(Great unconformity.)

Matsap Series (probably Waterberg Sandstone).—Chiefly quartzites and thin bands of pebbles.

(Great unconformity.)

Ongeluk Series.—Volcanic lavas, breccias, and tuffs, with a few cherty layers.

Griqua Town Series (Pretoria Beds of the Transvaal).—Ferruginous jaspers, banded magnetic rocks, sandstones, shales, cherts, thin limestones, and a glacial boulder bed near the top.

Campbell Rand Series (Dolomites of the Transvaal).—Limestones and dolomites, cherts and shales.

Black Reef Series.—Quartzites, flagstones, pebble beds.

(Unconformity ?)

Pniel Series (Ventersdorp Beds).—Volcanic lavas, breccias, tuffs.

(Unconformity ?)

Kheis Series.—Quartzites, mica schist.

There are also some intrusive rocks, diabases and very basic altered rocks.

The best account of the structure of this country given by the early explorers is certainly that of W. J. Burchell, though Lichtenstein mentions the occurrence of certain rocks and took to Europe the specimens of crocidolite and allied rocks described by Klaproth. Burchell says:—" The whole substratum of this part [Klaar Water, now Griqua Town] of the country, for many

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leagues northward and eastward, is a hard limestone rock of primitive formation; and on this rest the laminated argillaceous mountains."[1] He also describes asbestos and a mineral allied to "cat's eye."[2] A slight account of the rocks in the south-eastern part of Hay is given by R. Moffat,[3] who recorded the occurrence of sandstone in the Scheurbergen and Langebergen, and the fact that the rocks of the latter lie upon "ribbon-schist" (Griqua Town beds) and "mountain limestone south-west of Kuruman."

The first thorough geological description is that of G. W. Stow.[4] The present survey has led me to take other views than Stow's of several features, of which the most important are:—(1) The nature of the unconformity seen in the escarpment of the Kaap Plateau at Leij Fontein; (2) the relation of the Ongeluk volcanic series to the Griqua Town beds; (3) the nature of the Blink Klip breccia; and (4) the relation of his "Rooi Kopje" beds and "irregularly bedded jaspery rocks near Matsap." As to the unconformity at Leij Fontein, it appears to be a local break in the Campbell Rand formation; the Ongeluk volcanic rocks lie conformably upon the Griqua Town beds, and are separated from the Pniel lavas and breccias by the whole thickness of the Black Reef, Campbell Rand, and Griqua Town beds; the Blink Klip breccia is not an ordinary detrital rock, but it seems to have been formed by the collapse of Griqua Town beds, under the influence of gravity, and, perhaps, earth-movements, into hollows dissolved out of the underlying limestone; and the Rooi Kopje and irregularly bedded jaspers are parts of the Griqua Town beds, not separate formations.

There will be found below many references to Stow's work, but to have pointed out on every occasion agreement with or difference from his conclusions on matters of smaller importance would have unduly increased the length of this report.

The area dealt with includes some 4,000 square miles, which Stow covered in about two months; there are gaps in this area which I could not traverse last season, but even allowing for these, the three months (excluding days spent in fitting out and packing up, etc.) of mine were a short time for the area. For the time taken, Stow's results are remarkable, and they materially lightened the work of the present survey.

No further geological work seems to have been done in Hay till Mr. E. J. Dunn went there in 1885, for the purpose of "visiting the localities where crocidolite exists, ... particulars of

[1] "Travels in South Africa," 1822. Vol. I., p. 359.

[2] *Ibid.* p. 333.

[3] "Report of a Survey of a Portion of the Orange River, Eastward of Little Namaqualand," by R. Moffat, Esq., Government Land Surveyor, Cape Town, 1858. (G. 1—'58.)

[4] "Geological Notes upon Griqualand West," Q. J. G. S. XXX., 581-680, also "Cape Monthly Magazine," 1872, pp. 65-78.

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the geological formation in which the material occurs, and of procuring additional specimens of this mineral for the purpose of the Colonial and Indian Exhibition."[1] The results of this journey of Mr. Dunn's are shown in his "Geological Sketch Map of South Africa," Melbourne, 1887, in which all the sedimentary rocks from the eastern side of the Campbell Rand to the Kalahari are placed together in the "Lydenburg beds," and both the Pniel volcanic rocks and the Ongeluk volcanic rocks are called "Diabase, etc., later than the Lydenburg beds." Though as regards the Ongeluk rocks Dunn's map is an improvement upon Stow's, the inclusion of the lavas and breccias of the Vaal River valley in a group younger than the Griqua Town beds is not correct, nor is it an advantage to place together in one great group the Campbell Rand limestones, the Griqua Town beds, and the great quartzite group (Matsap beds) of the Langebergen in Hay and Ezel Rand in Prieska.

Since 1887 no map or memoir on the Hay Division, based upon further exploration, has appeared, but in 1899 the Cape Survey mapped the adjacent district of Prieska, and the results, so far as they concern the Campbell Rand, Griqua Town, and Matsap groups, upheld Stow's classification in Hay. The amygdaloidal diabase and associated compact rocks which occur mainly below the quartzites at the base of the limestones in the Doornberg area were at that time regarded as intrusive masses, but partly owing to work done in the Transvaal and near Vryburg, and an examination of the rocks under the microscope made since the 1899 Report was written, I have now no doubt that the Prieska amygdaloids are ordinary volcanic rocks, and represent the Ventersdorp beds of Hatch and the Pniel lavas and breccias. A recent examination of the T'Kuip hills confirmed this change of opinion, but there is now a difficulty in the arrangement of the lavas near Ezel Rand, which can only be solved by another visit to that locality, or possibly by a survey of the country on the north bank of the Orange River, a work which will probably be undertaken during the coming season.

As a whole, the rocks in the Hay Division are much less disturbed than the same rocks in Prieska. From the Kaap Plateau westwards as far as Matsap, the Campbell Rand, Griqua Town, and Ongeluk groups lie at low angles. The general trend is about N.N.E. The country between the Vaal River and the western limit of the Asbestos Mountains is probably the western or north-western limb of a very broad anticline, the axis of which is somewhere near the course taken by the Vaal, though the eastern or south-eastern limb is concealed under the Karroo formation as far up the river as the neighbourhood of

[1] Parliamentary Report. G. 8—'86. Cape Town, 1886, p. 3. A list of specimens collected will be found in the Catalogue of the Colonial and Indian Exhibition, London, 1886.

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Klerksdorp in the Transvaal.[1] The north-western limb of this wide anticline meets with the north-west trending rocks of the Doornberg range at Kliphuis, Enkelde Wilgeboom, and Buis Vley, where there is a small but broad dome-shaped mass of Campbell Rand beds, forming an inlier amongst the Griqua Town series. Below Enkelde Wilgeboom the Orange River runs more or less along the strike of the Griqua Town and Campbell Rand beds, where they have the Doornberg trend, as far as the poort through the Langeberg group of hills. It thus happens that at the localities nearest the Orange River the rocks in Hay, east of Langeberg, have the north-westerly strike of the Doornberg area; but further north, they turn parallel to the Campbell Rand and Asbestos Mountains.

Gentle synclinal folds with the prevailing N.N.E. trend bring in the Ongeluk series in the basins of Ongeluk-Witwater, Juanana, Abram's Dam, Paarde Vley, and Vlak Fontein, but on the western side of the Lucas Dam syncline the beds are overturned, so that the Ongeluk series dips under the Griqua Town beds, and the latter also dip westward towards the Langeberg, but the Campbell Rand group is not exposed west of Lucas Dam. The Langebergen are made of much bent Matsap beds, but whether on their eastern flank they merely lie unconformably upon the Griqua Town beds, as they do at their southern end on Witberg and at the south end of the Matsap outlier, or whether this limit is complicated by a thrust, is not yet known. In any case, the great disturbance of the Griqua Town beds near Lucas Dam is probably to be attributed to the earth-movements that affected the Matsap beds of the Langeberg. The previous disturbances that gave the Doornberg rocks their north-westerly trend are older than the Langeberg earth-movements, for the Matsap beds of Ezel Rand terminate the older rocks, and are only affected by the later disturbances that puckered up the Langebergen.

Of the later history of this area little can be learnt from the district itself; there are outliers of the Dwyka known along the southern edge, and there may be others under the sand further north, but the gap between the Matsap beds and the Dwyka, and the immense interval between Dwyka times and those represented by the high-level gravels, are not bridged by any rocks in Hay.

It should be remarked that in all cases of faulting where the presence and throw of the fault were ascertainable, excepting the second fault near Paling, the downthrown side lay on the east; no east and west faults of any importance were noticed.

[1] See the map attached to Molengraaff's "Geology of the Transvaal," Edinburgh and Johannesburg, 1904, and Pl. I in Hatch and Corstorphine's "Geology of South Africa," London, 1905.

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KHEIS SERIES?

On the farms O. 254, O. 259, O. 260, and O. 262, on the western side of the Langeberg, and separated from that range by sand-covered ground, there is a group of ridges trending S. 4° E.[1] The ridges are made of quartzites, with vertical or almost vertical dips, and the strike is parallel to the trend of the hills, viz., S. 4° E. There is a considerable divergence between the strike of these rocks and that of the quartzites of the Langeberg in their neighbourhood; for the rocks of the Langeberg strike S. 20°-25° W. The dip of the latter (Matsap beds) is towards E.S.E., along the western side of the range near Pad Kloof, though as the beds are much folded, the dip soon becomes reversed.

Where I crossed the ridges, along a line north-west of Pad Kloof, and about nine miles south of Witsands, there are three prominent ridges of quartzite, with parallel depressions filled with reddish sand, between them. The hills rise about 250 feet above the sand on the east side.

On the eastern side there are first massive quartzites, with a very high westerly dip. The colour is grey and pink. Some beds have numerous small dull white and pink grains in them, evidently weathered felspar. Magnetite is scattered through the rock, occasionally in sufficient quantity to give rise to a dark grey layer parallel to the bedding planes. Pyrites is present in parts of the rock, and is distributed irregularly through it.

Irregular false-bedding is prominent in some beds.

Small quartz pebbles are to be found in the rock, though they are much less abundant than the pebbles in the Matsap beds. These massive beds are followed to the west by thinner-bedded quartzites, which are separated by a sandy depression from the middle ridge, also made of thin quartzites, dipping vertically; the second depression is similar to the first, and the third ridge to the other two ridges. No outcrops were seen in the depressions, but there were pieces of quartz-schist lying in the sand of such size and form that they probably come from rocks concealed by the sand. The quartz-schist is made of quartz and sericite, and resembles rocks that occur in the hills near Brakbosch Poort, in Prieska.

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[1] All bearings in this Report, as in previous publications of the Geological Commission, are corrected for declination. In comparing any of these figures with those of Stow in Q. J. G. S., vol. XXX., it must be remembered that the bearings given in his text were not so corrected, for they do not tally with the strikes, etc., as laid down on the map attached to the paper. A correction of 25°—30° west will bring his bearings into agreement with his map and with the majority of the observations made by me. To correct Stows bearings they must be turned round about 25°—30° in the direction opposite to that taken by the hands of a watch; *e.g.* north would be north 30° west, and south-east would be east 15° south; etc.

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With the little information at present available, there is nothing further to be said in regard to the relationship of this group of rocks to the Matsap beds, than that they are almost certainly older than the latter. The absence of the jasper pebbles so frequently seen in the Matsap beds is striking, especially as these pebbles are rather more abundant than usual in the neighbourhood of Pad Kloof.

THE PNIEL VOLCANIC SERIES (VENTERSDORP BEDS).

The lowest beds seen on the surface between Barkly West and the Langeberg are the lavas and breccias in the valley of the Vaal River; these volcanic rocks undoubtedly underlie the Campbell Rand group and also the quartzites and gritty rocks on N.W. 4 (Herbert), which are referred to the Black Reef series. They consist of compact and amygdaloidal lavas, some of which are distinctly porphyritic, coarse and fine breccias, and tuffs. They are greenish blue in colour as a whole, but the more acid varieties are paler than others, which are evidently more basic.

These rocks have not been examined microscopically, but they have a general resemblance to the lavas and breccias which rest directly on the granite at T'Kuip near Omdraai Vley in Prieska, and which are described below.

It is interesting to note that the lavas and sedimentary rocks lying nearly horizontally below the Karroo formation at Kimberley have been pierced by a shaft at De Beers' mine, and that they rest upon a coarse granite at a depth of about 1,920 feet from the surface.

The T'Kuip Hills in Prieska.

Owing to a delay in travelling from Omdraai Vley to Prieska, I was able to spend a day on the T'Kuip Hills. This is the locality referred to in the Annual Report for 1899, p. 85, where it is stated that the amygdaloids send a long dyke-like intrusion through the granite of T'Kuip. I had time to make an examination of the south and central parts of the range, which is about eight miles long.

It is true that diabase dykes very similar in nature to the more compact lava of the volcanic group traverse the granite and gneiss, but the long extension mentioned in the Report for 1899 is really the basal portion of the volcanic group, overlain by a thick group of acid porphyritic lavas.

The granite rocks occupy the lower slopes of the hills on their eastern side; they are chiefly reddish gneissose rocks, in which biotite is abundant, but white fine-grained muscovite gneiss is also present, and there is much coarse pegmatite and massive granite in lenticular layers parallel to the foliation of the gneiss. The foliation planes run nearly vertically between north and

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N. 20° W., the strike varies within short distances. A dyke of compact diabase 20 feet in width runs in a general north-westerly direction through the gneiss towards the volcanic group about $2\frac{1}{2}$ miles north of the south end of the hills.

At the base there is a thick band of coarse breccias, made up largely of material derived from granite mixed with a greenish epidotic substance, probably of volcanic origin. Interbedded with the breccias are layers of very fine-grained green tuff and amygdaloidal lavas. The whole thickness of interstratified lavas, tuffs, and breccias at this locality is about 400 feet, and the highest beds are dark, coarse grits, containing occasional angular and subangular fragments of granite, quartzite, and vein quartz up to six inches in length.

These well-bedded rocks are succeeded by a great thickness of acid porphyritic lavas, which weather with a yellowish-white crust about 1-10th inch thick. In a hand-specimen these rocks have a close resemblance to some of the Beer Vley lavas. The matrix is blue-grey in colour and very compact; it contains porphyritic crystals of quartz and felspar, and a few amygdales of chalcedony. These acid lavas form the highest part of the T'Kuip hills. Their thickness must be very considerable, at least 500 feet.

The south end of the hills is made of basic lavas, which are much more amygdaloidal than the acid group above the breccias and tuffs. The basic rocks rest upon the gneiss of the eastern slope, and apparently underlie the breccias and tuffs

On the low ground west of the hills there are two outcrops of compact fine-grained breccia on the line of strike of the breccia band of the hills. These were the only outcrops I could find between the hills and Omdraai Vley, except a dyke of dolerite of the Karroo type. The low ground is sandy, and is strewn with lumps of surface limestone, such as underlies the soil over large tracts of country in the north of the Colony. There are also many boulders, which have weathered out from the Dwyka glacial beds, scattered over the flats. Their origin is proved by more or less well-preserved scratches or by their general shape; they are of various kinds of rock, but on T'Kuip and Omdraai Vley the majority are from the volcanic group, granite and crystalline limestone. The glacial boulders are also frequently seen in the valleys in the T'Kuip hills, so these hills have only been denuded of their covering of Dwyka within comparatively recent times.

Though the quartzites of the Black Reef series do not occur, or have not yet been found in the immediate neighbourhood, there can be little doubt that these volcanic rocks underlie the limestone (Campbell Rand group) which crops out in the Becha hills about three miles north of T'Kuip, and the quartzites appear on Zoet Vley, eight miles west of the T'Kuip hills. All these occurrences are inliers amongst the Dwyka series.

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BLACK REEF SERIES?

On the east side of the Kaap Plateau or Campbell Rand there is a hill range on Mr. Shaw's farm, N.W. 4 (Herbert), made of quartzites, grits, and greenish flaggy beds, which dip at an angle of 5° towards N. 20° E. They are over 200 feet thick. Owing to the necessity of travelling through the night to reach the river at this place, on my return journey from the Hay district, I could not follow the connection of these quartzites and some quartzites in the Sogo location ground seen the previous day, but they are probably part of the same group, for they both underlie the dark shales and the limestones of the Kaap Plateau, and are above at least the greater part of the volcanic rocks of the Vaal valley.

The Sogo quartzites are not so well exposed, but they appear to be intercalated amongst the volcanic beds of that locality. On N.W. 4 some 400 feet of volcanic beds are very well exposed, and they lie under the quartzites and grits; a small tributary of the Vaal has cut a valley along the junction of the sedimentary and volcanic beds, and the actual passage is not seen on that farm, but it may be a conformable one, for the dips of the two groups are about the same in direction and amount.

Between the Campbell Town kloof and the Sogo location the ground where the Black Reef series should crop out, if present, is covered with the Dwyka series and recent alluvium and gravels.

Until some work has been done in the Vaal River valley it will not be possible to decide definitely upon the relationship of these quartzites. Drs. Hatch and Corstorphine[1] place the quartzites interbedded with the volcanic rocks under Kimberley in their Ventersdorp group, and it is likely that the Kimberley sections are typical of a wide area westwards, for the rocks in that district lie at low angles.

THE CAMPBELL RAND SERIES.

This name was used by Stow[2] for the "siliceous and crystalline limestones" of the Campbell Rand, which clearly indicates the group of rocks referred to. In the Annual Report for 1899 there is a description of part of the Prieska Division, in which the term Doornberg series is used to include both the Griqua Town and Campbell Rand groups; while the Campbell Rand group was held to include not only the dolomitic limestones, but also the quartzites below these limestones, because there was no break in the succession.

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[1] Geology of South Africa, 1905, p. 152.
[2] Loc. cit. p. 613 and legend of the map, Pl. XXXV.

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There is no longer any use for the name Doornberg series, as the whole group is admitted generally to be an extension of the Transvaal system of Molengraaff[1] or Potchefstroom system of Hatch and Corstorphine[2].

The quartzites and other rocks of sedimentary origin which lie below the limestones of the Kaap Plateau can best be put into the Black Reef series, and the Campbell Rand series limited to the limestones, dolomites, and associated cherts, shales, and quartzites. This name will be used here in preference to "The Dolomite Series" as the Transvaal equivalents are called, on account of the priority of Stow's term and the fact that much of the rock is not dolomite, but limestone or a magnesian limestone with too little magnesium carbonate in it to be called dolomite.

The most characteristic rock in the series is the limestone. Many specimens collected are soluble in cold dilute hydrochloric acid, but there appear to be all varieties between these and dolomites which are not affected by the acid.

The usual colour of the rock is bluish grey, and the structure is crystalline. Near the intrusive dykes of diabase and more basic rocks the limestone is altered considerably; the diabase has turned the rock into white crystalline limestone, in which the colouring matter of the rock is gathered together in small black specks, and the more basic rocks have brought about greater alteration, which will be described in connection with those intrusions.

The cherts are grey or black, sometimes spotted with lighter patches, of which the origin is not yet known. Thin sections of these rocks have not yet been prepared; thin sections of cherts from the Campbell Rand beds in Prieska collected in 1899 show no organic structures.

The cherts are chiefly found to be interbedded with the limestones, either regularly or in nodular masses; they also occur in joints, usually perpendicularly to the bed planes.

There are three areas in our district where the Campbell Rand beds appear at the surface. First, and most important, is the Kaap Plateau or Campbell Rand; secondly a large part of the Field-cornetcy of Blink Klip, in the north-west of Hay; thirdly a small but interesting area cut through by the Orange River on O. 346, Wilgebooms Dam, Enkelde Wilgeboom, and Kliphuis.

(1) *The Kaap Plateau.*

The Kaap Plateau forms the eastern part of the Hay Division, the boundary of which coincides with the edge of the Plateau for some miles south of the Campbell Town kloof. In this neighbourhood the Plateau is about 24 miles wide. The

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[1] "Geology of the Transvaal," 1904.
[2] "Geology of South Africa," 1905.

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surface slopes very gradually towards the east, where the feature comes to an end at the foot of the Asbestos Mountains. On the East its edge forms a fine escarpment, overlooking the valley of the Vaal River.

During the past year the only work in this area was done during a journey from Griqua Town northwards to Kogel Been, and thence in an east-south-east direction to Campbell.

A visit was made to Leij Fontein, south of Campbell, with the object of seeing the section described by Stow,[1] where he found an unconformity at the base of the limestones, and rocks, which he took to be very much older, perhaps the equivalents of the Kheis beds, lying below it. I found an unconformity very well displayed in two kloofs south of Leij Fontein house and on the face of the escarpment. The lower beds, *i.e.*, those below the unconformity, consist of quartzites, limestones, cherts, and slightly micaceous shales. They dip at angles of from 10° to 35° in a westerly direction, between W. 10° S. and W. 14° N. I found no rocks that could be called schistose in the sense that the mica-schists rock of the Kheis series are so named. The micaceous shales are thinly laminated, but the mica flakes are not particularly abundant. The quartzites are rather glassy-looking rocks, with large quartz grains; they resemble some of the quartzites below the limestones west of the Doornberg in Prieska. Calcareous quartzites are also present, and in some of the thick limestones there are lenticular patches of quartzite. The limestones and cherts below the unconformity are not visibly different from those above; both on weathered and fresh surfaces they have the same appearance as many beds above. The unconformity is very sharply marked, and at several places the actual junction can be examined. There is no breccia or conglomerate at the base of the upper group, nor is there any sign of disturbance or slickensiding to indicate a thrust plane. The upper group of beds also has a lower dip than those below; the general direction of dip is towards W.N.W., but the dip varies both in amount and direction.

From the exposed part of the unconformity it is evident that some 300 feet of rock, or even more, were removed from the northern end of the section; and as the dip of the upper beds carries the unconformity below the surface south of Leij Fontein, the real value of the discordance is not ascertainable. The outcrop of the unconformity passes on to the surface of the plateau behind Leij Fontein, and I did not find it in the Campbell Town Ravine, where the rocks exposed on the sides of the kloof probably lie below it, if it persists so far.

North of the Campbell Ravine dark shales are frequently seen interbedded with the limestones and cherts. These shales

[1] Stow, *Loc. cit.* p. 619.

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were examined at intervals from Leij Fontein to Clearwater, and they appear to be suitable rocks for the preservation of fossils, but nothing was found in them.

Shales were rarely seen on the Plateau itself, though it is only in artificial sections that they can be exposed on such a plain.

The part of the plateau traversed by me is singularly featureless; no stream beds of any note were met with until the eastern escarpment was approached; a few small and shallow pans, waterless at the time of my journey, were the only depressions seen.

Towards the western edge of the plain there are a few small kopjes, on which the bedding of the limstones and cherts is well displayed. One of these kopjes has a remarkably regular step-form, like that described by Stow[1] from near Daniel's Kuil. The rock is jointed vertically and the bed planes lie horizontally; the limestone breaks and yields to solvents more readily along these planes than in other directions, so rectangular pieces are released, and the step-like form produced.

Chert is very abundant on the Plateau; it often crops out in irregularly disposed plates, which may be layers disturbed from their originally horizontal position by the removal of the enclosing rock, or they may be weathered out from more or less vertical joints. Loose fragments of chert, which must have been weathered out and left near their present positions by the solution of the limestone, are everywhere scattered over the surface. These rough pieces of chert are a certain sign of the presence of the limestone underfoot.

The dip of the Campbell Rand beds can be observed occasionally on the plateau, though in such a rock it is difficult to know that any particular outcrop, whose connection with surrounding rock is concealed, does not owe its inclination to solution of underlying beds. The wells give the best exposures. On O. 426, O. 425, and O. 41 the beds lie nearly horizontally; on Kogel Been, O. 43, and O. 38 they dip at low angles towards the Griqua Town hills (Asbestos Mountains), and the same is the case near Griqua Town. The actual junction of the limestones with the Griqua Town beds is concealed under gravels or tufaceous limestone between the south end of the Commonage at Griqua Town and Kogel Been, but there can be no doubt that the limestones pass westwards under the Griqua Town beds of the Asbestos Mountains.

(2) *The Blink Klip Field-cornetcy.*

The upper beds of the Campbell Rand group underlie a wide area in the north-west of Hay. They are brought up by a low anticline, with its axis trending about S. 25° W., and are evidently the southern end of a large limestone area in the Vryburg Division.

[1] *Loc. cit.* p. 658.

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Lithologically, the beds exposed are identical with those in the Kaap Plateau. They are best seen in the river bed which passes through Postmasburg.

On the eastern side of the area from the Barkly West boundary down to Kalk Fontein, the limestones dip at a low angle and conformably under the Griqua Town beds; the angle rarely exceeds 5°.

The southern end of the area probably lies between the Wolhaar's Kop hills and Kameel Fontein, but this ground is very much hidden under gravels.

The western side is marked by the northern continuation of the Wolhaar's Kop hills on M. 95 and M. 93. North of the last-named farm a complication is brought in by the fault on Paling, along which the Matsap beds are thrown down to the east, so that the limestones are lying against the Matsap beds of the ridge on which the north beacon of Paling stands. This limestone west of the Paling fault has only been seen at a few spots on the veld, but the abundance of tufaceous limestone in the neighbourhood shows that the beds extend further than the area shown by outcrops. Probably a second fault lies west of the limestone, for in the stream bed running west from Paling homestead the top beds of the Griqua Town series are seen between the Matsap beds and the syncline of the Ongeluk volcanic beds on Vlak Fontein. This second fault must have a westerly downthrow.

The Blink Klip breccia of Paling bounds the limestone as far as the Vryburg line, and the same rock occurs in outliers at various places in the neighbourhood. This area will be considered in more detail when the Blink Klip breccia is dealt with.

(3) *Enkelde Wilgeboom, etc.*

About five miles below Prieska village the Orange River traverses an irregular dome of limestone, which rises at a low angle from beneath the Griqua Town beds.[1] This broad anticlinal inlier lies in the angle between the Doornbergen, with their south-easterly strike, and the rocks of Hay, which strike north-north-east, at a place where the two directions of folding meet.

The Campbell Rand beds are lying at low angles, but their dip is rather disturbed, for it frequently changes. The uppermost 200 feet or so of the series are alone seen on the north of the river. Chert is not so abundant in the exposed sections as in the same rocks on the east and north of Hay.

The most interesting feature in this inlier is the passage upwards into the Griqua Town beds, which is very well exposed on the steep slopes on Klip Huis, below the trenches from which crocidolite is obtained. Beds of magnetic jaspers are inter-

[1] That part of the area on the south side of the river is mentioned on p. 78 of Ann. Rep. Geol. Comm. for 1899.

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bedded with the blue crystalline limestones towards their upper limit, and these jaspers are in no way different from the similar rocks which lie above the limestones. There is no sign of any discordance or any subsequent disturbance of the strata along the exposed part of the junction on Klip Huis. The top of the Campbell Rand group was taken at the top of a thin layer of a peculiarly light white and pink rock about 18 inches thick. This is a peculiar rock; it is very light, owing partly at least to the minute pores in it; it appears to be a hydrous aluminous silicate, such as kaolinite, as it contains alumina, silica, and water, and the powder under the microscope is seen to consist of very minute flaky pieces of a transparent mineral, with weak double refraction.

Thickness of the Campbell Rand Group in Hay.

No estimate with an approach to closeness can be made of the thickness of this group. The width of the principal area of the Kaap Plateau, the present uncertainty as to the position of the base there, and of the dips on the Plateau, prevent the measurements having any value. In Prieska[1] the group was found to be about 5,000 feet thick, and it may be as thick in Hay.

THE GRIQUA TOWN SERIES.

This group of rocks occupies a very wide area in Hay. It forms the low range of hills called the Asbestos Mountains, and a further wide area south of the great syncline of Ongeluk and Witwater; west of this syncline it is more important than any other group until the Langeberg is reached.

On lithological and stratigraphical grounds those rocks called by Stow Blink Klip breccia, and those mentioned as "the red jaspers of the Rooy Kopjes," and "irregularly bedded jaspery rocks near the Matsap hills," are here included in the Griqua Town series.

Description of the Rocks.

The characteristic rock of this group is a very hard siliceous rock, with more or less magnetite in it. The colour varies greatly, pale yellow, brown, red, and black are the most usual, but the differently coloured rocks do not often occur at the same place. The colours are due to the state of the iron; where the iron is all in the form of magnetite the rock is black; haematite and limonite colour the red and the yellow and brown rocks. These rocks are usually called jaspers. No thin sections have yet been cut from the Hay rocks belonging to this group, but as the same beds occur in Prieska, and sections from them are

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[1] Ann. Rep. Geol. Comm. 1899, p. 80.

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available, the characters can be described from the Prieska specimens.[1]

The jaspers are usually banded; the layers of differently coloured rock vary from the thinnest visible streak up to a couple of inches in thickness. The black magnetite layers are interbedded with yellow, brown, or red jasper. Rarely the red rock is interbedded with the yellow or brown.

An average specimen of the brown jaspers (463, T'Dyzega, Prieska) shows under the microscope a transparent base of very minute quartz areas, just like the cherts in the Campbell Rand group, and a great quantity of brown amorphous matter, which must be hydrated oxide of iron. In the smallest particles the iron ore is transparent, and yellowish in colour. The iron ore occurs so abundantly in certain bands that they are almost opaque, but minute clear spaces are to be seen, especially under a high power, and these spaces are patches of chert. In the clearer layers the iron ore occurs in lumps with irregular boundaries and in very small flakes and spots throughout the chert. These small flakes may lie entirely within a crystalline quartz grain, or they may extend from one into another. They do not often lie between two grains.

A section from a red and black banded (472, from Nauga, Prieska) rock shows that the magnetite is confined to well-defined layers, and that it rarely occurs isolated in the red layers, though there are streaks formed by a layer of single particles running through the red rock. The magnetite is the form of irregular granules. The clear base is chert, as in the brown rock. The red layers are sharply defined, but oval or nodular patches of the red rock occur within the magnetite layers. The red colour is given to the rock by red dusty matter and extremely fine red needles. A yellowish dusty material is present in small amount.

A rock from Nauga (469 and 470, Nauga, Prieska) shows some very interesting features in addition to those characters mentioned above. The bulk of the rock is composed of magnetite and chert, but there is a fair amount of brown hydrous oxide also; with these there are two other minerals, one is a brilliant green biotite, in fair sized flakes, and the other is crocidolite, in very small crystals. The larger crocidolite crystals are big enough to measure the extinction angle on (16°-18° with the length of the prisms), and to determine the pleochroism on, violet parallel to the direction of least elasticity, which is the long axis of the crystal, and green across the prisms.

[1] The specimens selected come from the Doornbergen and not from the magnetic quartzites associated with the gneiss further west. In the 1899 Report the western outcrops are described as belonging to the Griqua Town series, but this view must be given up. The recent work of Mr. du Toit in Vryburg and Mafeking has thrown much light on the Prieska rocks, and the western outcrops of magnetic quartzites, etc. are very probably much older than the rocks of Doornberg.

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The heavy blue and green rocks associated with the crocidolite worked on Westerberg and found at the south end of the Doornberg range also occur frequently in Hay. When a piece of the blue rock is crushed and the powder examined under a high power, the smaller fragments are seen to have a fibrous structure and the same optical properties as crocidolite. The green rock has less crocidolite in it than the blue, and it is largely made of a greenish mineral, which has not been determined. The very dense dark blue rock, which is often found with a highly polished black exterior, and which is more conspicuous in the form of pebbles in the Orange River gravels and fragments lying on the surface of the ground far from outcrops of similar materials,[1] gives a powder entirely formed of small crocidolite fibres. The specific gravity of two specimens of the blue rock is 3·30 and 3·27. This heavy blue rock is evidently the same as that collected by Lichtenstein on the Orange River and analysed by Klaproth,[2] who gives the following figures:—

Silica	50
Iron protoxide	40·5
Lime	1·5
Soda	5
Water	3
Specific gravity	3·200

He called the rock "Blau-eisenstein."

Hausmann[2] distinguished between an earthy and an asbestos-like variety of the mineral, which he named Krokydolith. The two varieties were analysed by Stromeyer[3] :—

	Earthy variety.	Asbestos-like variety.
Silica	51·64	50·81
Iron protoxide	34·38	33·88
Manganese oxide	·02	0·17
Magnesia	2·64	2·32
Lime	·05	0·02
Soda	7·11	7·03
Water	4·01	5·58

The earthy variety is probably the same kind of rock as that collected by Lichtenstein, though not identical with it. The asbestos-like variety is certainly the mineral that is now being worked in Prieska and Hay.

[1] Pieces of this rock picked up on the veld are often thought to be meteorites by the farmers. One man assured me he saw a stone fall about 500 yards away, and on digging at the spot disturbed he got the lump of crocidolite, which he gave me.

[2] Klaproth, M. H. "Beitrage zur chemischen kenntniss der Mineral Körper," 1815. Vol. 6, p. 237.

[3] Quoted by Hintze, "Mineralogie," p. 1265; Gött. gel. Anz. 1831, p. 1585; Stromeyer, Pogg. Ann. 1831, 23, p. 153.

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The heavy green and blue rocks are, from their mode of occurrence, certainly sedimentary rocks which have undergone great mineralogical alteration since their deposition. They are interbedded with jaspers, and also with strata that are more like normal sedimentary rocks. Whether the blue beds are made of the debris from lavas, either in the form of fine tuff or river-borne detritus, or whether they were deposited under other conditions, is not definitely known; the occurrence, however, of ferruginous sandstones and calcareous rocks in the upper part of the Griqua Town series on certain farms in Hay, while elsewhere the beds on the same horizon are the heavy green and blue rocks or red and brown jaspers, makes it probable that further investigations will prove the derivation of the crocidolite rocks from ferruginous sediments.

The hard yellow alteration product of crocidolite was also taken to Europe by Lichtenstein and analysed by Klaproth, who called it "Faserquarz."

He gives the figures:—

Silica...	98·50
Oxide of iron	1·50

Several later analyses are given by Dana in his "System of Mineralogy," 1894, pp. 400 and 401, which show slightly less silica and a larger quantity of iron oxide (mostly the sesquioxide). Dana also gives an analysis by Hepburn of the soft yellow mineral called griqualandite, an intermediate stage between crocidolite and the very siliceous fibrous quartz mentioned above. Hepburn's analysis gave:—

SiO_2	56·75
Fe_2O_3	37·64
FeO	1·09
MgO	·10
H_2O	5·23

Griqualandite is not often met with; all the specimens I have seen come from the left bank of the Orange River, between Buis Vley and Westerberg. The Cape Asbestos Company found a fairly thick layer of it in one of their cuttings on Westerberg. Griqualandite is brittle, golden to coppery yellow in colour, and is of no use for the purposes to which asbestos is put.

The asbestiform crocidolite, or one of the series of products of oxidation and silicification derived from it, are known from almost every farm situated on the Griqua Town series in Hay, though the mineral is worked on a few farms only. During my survey work was being carried on at Klip Huis, Koegas, and Leelyk's Staat in Hay.

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These minerals occur in layers parallel to the bedding planes of the enclosing rock; where the rocks have been fractured or much bent small veins of crocidolite traverse them at an angle, and in most cases a connection between such a vein and a layer parallel to the bedding can be traced. The occurrence of the mineral in this form, the thin layers of dusty matter sometimes seen in the fibrous mineral traversing the fibres in a plane parallel to the bedding of the enclosing rock, together with the existence of beds of the earthy or compact variety, point to the development of the fibrous mineral from the compact variety in place. If this be a correct interpretation, there must be intermediate stages in existence, but the only place where I have seen an intermediate step is near Claradale (Riet Fontein or T'Aap). At this place there are roughly fibrous blue rocks, which have a general appearance of the compact variety of crocidolite, with the strongly developed cleavage in several planes, which intersect each other in one and the same direction. This blue rock consists of a greenish non-pleochroic mineral and of crocidolite, but the latter mineral has not the length of fibre or the parallelism of the asbestos. The direction taken by the incipient fibres is inclined at an angle of 30° or so to the bed planes, whereas in the asbestos this direction is perpendicular to those planes, or nearly so, and it is rarely inclined 45° from the perpendicular.

In Prieska[1] it was noticed that crocidolite (blue asbestos) occurred along with the heavy blue rock, and the oxidised and silicified varieties with the jaspers, indicating a parallel change in the two materials. In Hay, however, there are places where the blue asbestos is worked in the hardest magnetic jaspers. At Klip Huis the blue asbestos (crocidolite) occurs, together with silicified and oxidised varieties, in yellow and black magnetic jaspers. In several trenches opened up there by the Cape Asbestos Co., layers of the intensely hard yellow and blue fibrous mineral change into the soft blue form of crocidolite at a distance of two or three feet from the outcrop, and the soft mineral is obtained on a commercial scale under these conditions. It is by no means in every case that the hard variety changes thus, and the soft blue variety is more frequently obtained by following up outcrops of the same. At Kranz Fontein and at The Kloof I did not find a similar transition in the open workings, made for the purpose of obtaining the hard varieties, though some of the cuttings had been carried far enough to exhibit the change if it had taken place within the same distance as at Klip Huis.

These facts show that the change of condition is not due to reactions going on at the present time, but that the gradual passage from the hard to the soft varieties at Klip Huis is probably accidentally connected with the presen[illegible] .rface.

[1] Ann. Rep. Geol. Comm. for 1899, p. 81.

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The change from the unoxidised to the oxidised and silicified rocks has taken place under conditions that have not yet been explained, but which are not directly connected with the disturbances which have affected the area. Both the oxidised and unoxidised—the yellow and blue—rocks show, in several areas, the effects of extensive earth-movements, and then, again, they both lie comparatively undisturbed over wide stretches of country.

The chief changes are the oxidation of the blue ferrous compounds and the addition of silica. Whether silica has been added from outside or whether it has merely travelled from certain beds in the series to others is not yet clear; it is evident, however, that the layers of yellow fibrous quartz have been enriched by nearly 50% of silicia from outside themselves.

The cherts in the Griqua Town beds are like those in the Campbell Rand series. They are particularly abundant near the top of the group. In some cases they contain octahedra of magnetite, as on Tolo.

Limestones are not frequently met with, but they occur in the hills near Rooi Laagte and at several places in the Koegas Field Cornetcy, always within 300 feet or so of the top of the series. In character they are like many of the Campbell Rand limestones, blue or grey in colour, crystalline, and they weather with the same brown irregular surface that is considered characteristic of the Dolomites of the Transvaal, and which has given that rock the name of Olifant's Klip.[1] These Griqua Town limestones are not thick, rarely over 12 inches.

On Rooi Laagte there are sandstones and shales containing calcareous matter and much iron; the latter is concentrated on each side of joint planes and along some of the bedding planes. Interbedded with the calcareous sandstones there are rocks in which silicification has taken place, but not to the same extent as in the jaspers; the iron in this rock is in the form of limonite.

The Rooi Laagte rocks are much less altered from their original condition than are the Griqua Town beds at any other locality at which I have seen them.

There is no reason to doubt that the banding, due to high content of magnitite, or to the presence of limonite or haematite, indicates the original bedding planes of the rocks. The conformity of such layers with beds of less altered rock is a conclusive proof of this point in the areas where the highly and less altered rocks occur together, and the assumption that the bands are beds or laminae in those areas where only highly altered rocks occur leads to results, as regards structure, that are in agreement with what would be expected.

[1] This mode of weathering is found in all the crystalline limestones of Pre-Cape age known to me in Cape Colony, viz., those in the Malmesbury beds of Van Rhyn's Dorp, the Piquetberg and Worcester districts, and the Cango limestones.

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The Glacial Beds.

The conglomeratic rocks which occur at or near the top of the Griqua Town series are particularly interesting, because they contain distinctly striated and flattened pebbles and boulders, which certainly owe their characteristic shape and scratches to glacial action.

The matrix is yellow, brown or red in colour, according to the state of the iron oxide present, but in a few cases a white or pale grey rock is met with three or four inches below the surface. The outcrops are generally very dark brown or red, almost black, in consequence of the concentration of iron oxide. The white rock seems to be due to the leaching out of the colouring matter; the subsequent veins in its neighbourhood are of white quartz, and the white patches of matrix appear to be irregular in shape, but more or less confined to parts equi-distant from visible joints and the outer surface. In the glacial beds on Juanana there is less iron oxide than elsewhere, and a thin section (1,457) shows a fair amount of carbonates, probably calcium carbonate, with little or no magnesium carbonate, distributed through the rock in patches. These patches are in many cases sections through rhombohedral or scalenohedral crystals; in others, the boundaries are quite irregular. In ordinary light they are scarcely distinguishable from the rest of the matrix, for they enclose the dusty matter and grains of quartz, etc., just as the usual matrix of the rock does. The patches of calcite rarely reach a millimetre in length. The usual matrix is apparently siliceous; it looks like a chert with very fine texture; but it encloses so many small particles of indeterminate substances, as well as very small grains of quartz and other minerals, that its cherty nature is masked to a great extent. In several places, however, the rock, as a whole, breaks with a cherty fracture. The chief constituent, in the form of small angular grains, is quartz, but chert fragments are fairly abundant, as would be expected from the amount of that substance in the rock in the form of pebbles. Felspar is represented by a few grains of repeatedly twinned acid plagioclase, such as is found in many granitic rocks; microcline is absent from this section, and from the section of the grits associated with the glacial beds on Juanana (1,456). There are no other determinable fragments, though one brown fragment may be tourmaline. There is much greenish chloritic mineral scattered through the matrix; but it is probably not an original constituent of the rock.

No sections through the red and brown rocks have been made, but, so far as can be judged from hand specimens, these differ from the Juanana rock merely in the greater abundance of iron oxides.

The boulders reach a length of about a foot, and the great majority of them are cherty rocks; a few grits and fine-grained

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quartzites have been noticed, but not a single specimen of granite, gneiss, diabase, or other igneous rock has been found. Limestone pebbles have not been seen in the rock, but there are occasional cavities with smooth surfaces which may represent limestone pebbles now removed by solution. These cavities are often partly filled by hydrated iron oxides. In the red rocks, specular iron is very often seen in such holes, and also in the general matrix.

The hardness of the matrix makes it difficult to break the boulders from the rock; generally the fracture passes more readily through the boulder than round it. Several specimens were, however, broken out, with parts of their surfaces exposed to view, and some of these are covered with striations. The best examples of striated stones, however, were found on the surface, they having been loosened from the matrix by the effects of changes of temperature and the action of air and water. In some cases well striated blocks were found with the original matrix still covering parts of the striated surfaces in such a way as to prove that the scratches were on the rocks before they were removed from the matrix.

The scratches are excellently preserved on the cherts; the surface of a flattened oval pebble may show several sets of scratches, or a few deep scorings crossing a set of finer scratches. In such cases the pebble has not been greatly changed in form during the production of the scratches; in many cases a part of the boulder has evidently been removed by the same process which made the scratches, and it is now left with one or more flattened surfaces covered with scratches. The striated pebbles and boulders, so far as their shape is concerned, may be matched by many striated stones from the Dwyka series, or from the more recent tills of other countries, and there is no reason to doubt the glacial origin of the striated stones from the Griqua Town beds of Hay.

The glaciated boulders were obtained at many places both on the west and east sides of the great syncline of volcanic rocks which occupies a large area in the middle of the district. The localities will be mentioned later.

In places the pebbles are sufficiently abundant to give the rock the character of a conglomerate, but more usually they are scattered at various intervals through the fine-grained matrix.

The origin of the boulders is a question which cannot now be considered with advantage, because the rocks which make the boulders yet studied are only cherts and fine grits, and so far as our present knowledge of the country goes, they do not lend themselves to a solution of the problem.

Amongst the boulders in the glacial rocks there are often to be seen flattened oval lumps of chert, with a distinct nodular appearance, sometimes with a keel-like edge all round them and other signs, such as an indistinct banding, of having been

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isolated masses in clayey or calcareous rocks. The shape of these lumps of chert is not that of water-worn pebbles, though there are numbers of obviously water-worn chert pebbles in the same beds, but they are more like the oval limestone concretions in some marls and shales. I obtained several of these oval cherts with well striated surfaces.

Distribution of the Griqua Town Series.

(1.) *The Asbestos Mountains.*

From the banks of the Orange River above Kliphuis the magnetic jaspers of this series stretch in a north-north-easterly direction past Griqua Town and the Peiser mine into the Barkly Division. This belt is the Asbestos Mountains of the maps, but although the ground rises rather sharply from the country on either side, the hills do not reach a greater height than about 700 feet above it. Only a small part of this area has been traversed as yet; the south end is cut up by more or less longitudinal valleys, partly filled in with the Dwyka formation, and the modern valleys cut across these old lines of drainage. The top of the range is fairly flat, although the rocks do not lie horizontally, but are at places sharply bent.

A section through Krantz Fontein and neighbouring farms is shown in Fig. 1. The Griqua Town beds at this end of the range are chiefly thin banded magnetic jaspers; the jasper is most frequently yellow or brown, and different layers show slightly different tints. Dull red layers are often seen, but the red rock is less abundant than the brown and yellow. Occasionally the rocks are fine-grained sandstone, rich in limonite and magnetite, more rarely containing haematite. These softer beds give rise to caves on the sides of the kloofs.

On large surfaces of the jasper, undulations, which look very like ripple marks, are to be seen at places. It is sometimes the case that these ripples affect only a single layer of rock, and the succeeding bed fills up the hollows and itself presents a plane surface; in such cases the markings are original, and were doubtless caused by currents in the water under which the sediments were laid down. In other cases, however, the markings are of subsequent origin. At the head of the kloof leading southwards to the homestead on Krantz Fontein, there is a band of corrugated rock, of which the surface at any horizon within the band looks as if it were covered with ripple marks. I traced this rock, which lies nearly horizontally, for over 100 yards from east to west. It is two feet thick where best exposed, and the overlying and underlying rocks are precisely similar, but without corrugations. The rocks consist of thinly banded magnetic and brown jaspers, with numerous layers of yellow fibrous quartz (altered crocidolite), which are continuous for at least

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several yards in the flat-bedded part of the rock. The corrugations extend with the same axes, *i.e.*, along the same lines, right through the two feet of corrugated rock; the length of the waves is about nine inches, and their amplitude one and a half at most, but this amplitude decreases gradually above and below, bringing about the passage into the flat-bedded rock. The altered crocidolite is thicker in the crests of the waves than elsewhere, and sometimes does not reach the troughs at all. The trend of the undulations is about the same as that of the greater folds on the same farm, *i.e.*, N. 20° E.

Along certain lines the jaspers on Krantz Fontein are brecciated. One band was followed for 400 yards; it is made of pieces of the jasper, set in a siliceous and haematitic matrix; the broken rock is 20 feet wide at the most; it gives rise to large rounded outcrops, not unlike those of dolerite dykes in a dry climate.

Certain beds on Krantz Fontein and Wilgebooms Dam are very full of magnetite, and are black in colour. It is an interesting fact that in this rock the crocidolite and the yellow mineral resulting from its alteration are represented by white fibrous quartz.

A good section through the Asbestos Mountains is afforded by the valley which runs diagonally across the range from Claradale to the Orange River. This valley was only examined as far as Kafir Krantz. The beds are not so disturbed as are the same rocks on Krantz Fontein. The steep hillsides south of the valley on the Kloof are noted for the variety of the alteration products of crocidolite which have been obtained there.

Fig. 1.—Section through Krantz Fontein to show the relation of the limestones to the Griqua Town beds, and of the Dwyka outliers to the older rocks. Horizontal distance, 12 miles; horizontal to vertical scale, 1:10.

From Punt northwards to the Barkly West Division the Griqua Town beds dip west-north-west under the volcanic series of Ongeluk, but only that part of the line of junction north of Manby (O. 7) and south of Peiser's mine has yet been examined.

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An account of the section across the range from Griqua Town to Taaibosch Fontein will probably illustrate its structure for a considerable distance both to the south and north of Griqua Town.

The lowest beds seen near Griqua Town are yellow jaspers, with thin layers of magnetite. The junction with the underlying limestones of the Campbell Rand series is not seen here, and the lowest of the banded jaspers are considerably contorted and broken, though the beds seen on the lower slopes of the hills are not disturbed in a similar way. I have not seen a good clear section near Griqua Town, in which the nature of this local disturbance can be ascertained, but such a section is certainly exposed at "Ramaje's Kop," near Daniel's Kuil, described by Stow,[1] which has not yet been visited by the Geological Survey. Stow says the jasper rocks lie in "small trough-like hollows" in the undisturbed limestones of the Campbell Rand group, and that the jasper rocks are greatly contorted. He attributes the disturbance to pressure acting from the west, but does not account for the undisturbed condition of the limestone. The local disturbance of the base of the Griqua Town beds was seen again near Groen Water, and has taken place on a gigantic scale in the Blink Klip Field Cornetcy, in connection with which the matter will again be considered. At Enkelde Wilgeboom the succession from the limestones upwards is quite normal. At all these places the limestones themselves are not disturbed; they lie flat or dip at moderate angles under the jasper rocks. Neither at Griqua Town or elsewhere are there signs of thrust at this horizon, unless the dislocation of the jaspers be considered evidence to that effect. The explanation of these local disturbances is probably to be found in the collapse of the lowest jaspers into cavities formed on the surface of the Campbell Rand group by solution.

The banded jaspers have a regular dip towards the west-north-west, but the angle varies up to 35°; it is more usually from 5° to 10°, sometimes, especially towards the west side of the range, less than 5°. Softer beds, ferruginous sandstones, and shales are occasionally met with where small exposures have been made along the road-side; red jaspers are rarely seen in this neighbourhood. A well-marked escarpment, with a krantz of varying height, rises on the right side of the valley on the eastern part of Taaibosch Fontein; this escarpment is formed by the glacial beds, and excellent sections through them are readily found. These beds make three prominent hills a few miles to the north of the Taaibosch road. The kopjes, one of which is the Orpen's Kop mentioned by Stow,[2] are near

[1] Q. J. G. S. XXX., p. 665, and Pl. XXXIX., fig. 8.
[2] *Loc. cit.* p. 627.

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the road from Griqua Town to Moss Fontein, and one of the boundary beacons of Griqua Town Commonage is on one of them. The glacial beds are brown, and they vary in texture from place to place according to the amounts of iron ores and silica in them. They are very tough rocks or splintery, and the contained pebbles and boulders are not easily got out. The weather has loosened many of the boulders, and beautifully striated stones are to be obtained amongst the outcrops. In places the inclusions are sufficiently numerous to make the rock a conglomerate, but usually the boulders and pebbles are scattered at considerable intervals through the matrix, in a way that recalls the distribution of the boulders in the southern Dwyka and in the glacial rock in the Table Mountain series near Clanwilliam. The boulders are made of cherty rocks and fine-grained grits. These beds are well displayed on the dip-slope down which the road to the house on Taaibosch Fontein is carried. There is an alluvial flat separating the glacial beds from the igneous rocks of the main valley on Taaibosch Fontein, but they certainly dip towards the latter. On the west side of this valley there is a fault, along which the beds are dropped on the eastern side, so that the upper part of the Griqua Town beds and the lowest portion of the Ongeluk beds are repeated. It is possible, however, that the igneous rocks of the Taaibosch Fontein valley are intrusive, and do not belong to the Ongeluk lavas.

The thickness of the Griqua Town series, as calculated from the width of outcrop and average dip of the beds a few miles north of the village, is 2,500 feet. Along this line the beds are probably less disturbed than further south, and unless there are strike faults with downthrow to the east, the above estimate is near the truth.

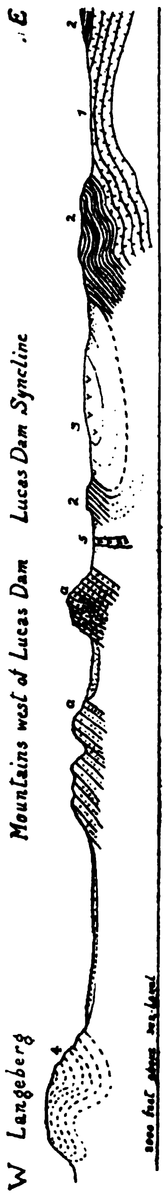

FIG. 2.—Section through the Langeberg area in the N.W. corner of Hay. 1. Campbell Rand series. 2. Griqua Town series. 3. Ongeluk series. 4. Matsap beds. 5. Dyke of dolerite or diabase. *a*. Quartzites, slates and conglomerates of uncertain age. Distance, 17 miles; horizontal to vertical scale, 1:2.

(2.) *The Koegas and Paarde Kloof Field Cornetcies.*

The Griqua Town beds in the east of Koegas Field Cornetcy are continuous with those in the south end of the Asbestos Mountains. The most interesting area is that between Niekerk's Hope and the Juanana syncline of volcanic rocks. The Griqua Town beds are here much less silicious, and have less iron oxide in the form of magnetite and haematite than in the Asbestos Mountains. They lie at low angles, and give rise to many Kopjes, which recall by their shape the dolerite or sandstone capped hills of the Karroo.

The hill on which the N.W. beacon of Rooi Laagte (O. 351) stands is a typical example of these Kopjes.

The following is a roughly measured section taken on the eastern side of this hill:—

Brown calcareous sandstones, with much iron, partly in the form of carbonate; weathers with joints marked by concentration of iron oxide	20 feet.
Shales with thin beds of crystalline limestone and sandstone...	100 „
Hard blue clayey sandstone, making a strong rib on the hillside	2 „
Shales and thin sandstones	90 „
Hard blue sandstones, slightly calcareous ...	30 „
Shales and their sandstones	70 „
Hard grey sandstones	4 „
Shales and sandstones...	80 „
	396 feet.

The shales which form so large a part of the hill are dark rocks, rather hard but thinly laminated, and some beds at least contain carbonates. At this locality the rocks dip at about 3° W.N.W., but a shallow syncline brings in the same beds on the crests of some hills between Rooi Laagte and Juanana; just east of Juanana they dip down at angles of from 3°—5° under the volcanic rocks, and the glacial beds intervene between the two.

The country south-west of Juanana, as far as Hakschin, has not yet been mapped.

Immediately west of the Juanana volcanic rocks the uppermost beds of the Griqua Town series seen are thin limestones, including a breccia with limestone matrix, brown, blue, and green heavy ferruginous sandy rocks often finely banded. There is a strip of ground covered with sand between the volcanic beds and these western sedimentary rocks and the glacial beds have not been seen there. There are considerable differences between the Rooi Laagte beds and these, but the change is evidently an intermediate stage, leading to the magnetic and siliceous rocks so characteristic of the Griqua Town series.

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On Randjes, Waterkloof, Stinkwater, and Tolo, the Griqua Town beds again dip down under a syncline of volcanic rocks. This area, as far westwards as Piljaar's Poort, was visited before the evidences of glacial action in the top beds of the series had been discovered, and so the glacial beds were not looked for. Whether they exist there is at present uncertain.

On Tolo there is a fine section through some 700 feet of the upper part of the series; heavy blue and green rocks mostly, with some thinly laminated beds; thin limestones and dull red haematitic rocks occur, as well as fresh cherts containing small crystals of magnetite. The hills on which this section is found rise some 500 feet above the direct road from Abram's Dam to Griqua Town, and they lie on the northern side of it. From the top one has an excellent view of the broad anticline of Griqua Town beds, with its axis running about S. 10° W., which carries the beds under the volcanic rocks of Juanana on the east and of Abram's Dam, etc., on the west. Towards the north there lies a rather rugged tract of country, evidently formed by Griqua Town beds lying at low angles.

West of the Abram's Dam syncline heavy ferruginous rocks, accompanied by thin blue dolomites, rise from under it, and below them there are red and brown magnetic jaspery rocks. This succession is repeated on account of the westward dip of the beds before the Paarde Vley syncline of volcanic rocks is reached.,

West of the north end of this syncline the Griqua Town beds are bent into another anticline, which brings them down under the volcanic beds on Leelyk's Dam.

South of the Leelyk's Dam syncline there is a wide area of the Griqua Town beds on the farms Grasgat, Kwakwàs, Pypwater, Hounslow, Koegas, and Leelyk's Staat. In this area the beds again assume the same characters as they have in the Asbestos Mountains and the Doornbergen, but flanking the west side of the Paarde Vley syncline there are thin limestones, interbedded with cherts and haematitic rocks near the top of the series. On Koegas, Hounslow, Leelyk's Staat, and Pypwater the bulk of the rock is brown and yellow magnetic jasper, with layers of the heavy blue rock containing much crocidolite distributed through it. Crocidolite, in the form of asbestos, as well as the oxidised and silicified varieties, occurs on these farms, and is worked by the Cape Asbestos Company, to whose manager, Mr. T. Olds, I am indebted for much information.

In this part of the district the Griqua Town beds become considerably disturbed, and near the Orange River the prevailing strike is nearly north-west, instead of north-north-east, as in the Asbestos Mountains and the rest of Hay. This change of strike shows that the rocks are here folded parallel to the Doornberg folds, and the Orange River has made a passage for itself along the Campbell Rand beds below the sharp bend on O. 322.

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On Leelyk's Staat, Stilverlaats, and the two farms called Witberg (O. 315 and O. 316), the colouring matter in the jaspers is very often haematite.

A few inliers of magnetic haematite schistose rocks occur on Piljaar's Poort, rising out of the sand between the bifurcated southern end of the Langeberg ridge. These schistose rocks are probably sheared Griqua Town beds; with them are associated some pink and white cherts, with dark magnetic and haematitic layers. The isolated outcrops in this sandy country cannot be directly connected with any large mass of Griqua Town beds, but their strike is parallel with that of the Griqua Town series on Stilverlaats and O. 315 (Witberg).

In the neighbourhood of Matsap, on both sides of the outlying range of Matsap beds, the Griqua Town beds are well developed, though their base is not seen. Between the Matsap ridge and the Langeberg they form a wide tract of hilly country, which includes the "ridges near Potgieter's" of Stow's paper,[1] and on the east of the Matsap ridge lie the Rooy Kopjes[2] of the same author. Both these formations were separated from the Griqua Town group by Stow, but there is no good ground for doing so.

In lithological characters the brown, yellow, and reddish banded and magnetic jaspers of the hills between the Matsap ridge and the Langebergen can be matched in the Asbestos range and the Doornberg; the heavy blue rocks containing crocidolite are exposed on Witdraai and O. 203. Both the asbestiform crocidolite and its alteration products are found in the same hills. Though neither the top or bottom of the series has been seen in that neighbourhood, I saw from the hill tops an area to the south-south-west where these strata appear to dip under the north end of the Ongeluk volcanic series of the Abram's Dam syncline. Lack of water in that area prevented the work from being completed last season.

These hills are a broad anticline, rather irregular in structure, stretching north-north-east. The rocks then dip under the Matsap ridge, though faults probably complicate the conditions there.[3]

On the east side of the Matsap ridge the red magnetic jaspers reappear. They are especially well-exposed round the south end of the ridge, where the Matsap beds lie upon them. It is in this neighbourhood that the glacial conglomerate near the

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[1] *Loc. cit.* p. 663, also pp. 633-637. "Potgieter's" is the farm now called Plaatjes Dam or Oudmeides Kloof.

[2] *Loc. cit.* p. 663, also pp. 629-632.

[3] Stow considered that the red jaspers were older than the Matsap beds, and that the yellow and brown jaspers were younger than the same formation. He took this view because red jasper pebbles are found in the Matsap beds, and his experience led him to think the brown jaspers on either side of the Matsap ridge lay above the Matsap quartzites, *loc. cit.* pp. 630 and 635; also Cape Monthly Magazine for Aug. 1872, p. 69.

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top of the series is very well exposed; it occurs in a syncline between the Ongeluk volcanic rocks (seen on Van Nels Dam, Prairie, and Dell, etc.), and the Matsap ridge on the farms Lang Kloof, Water Kloof, and Koodoo's Kloof. It is overlain by some highly haematitic rocks and cherts; the junction with the volcanic rocks to the east is hidden, but the dip is towards the latter on Range and Eden. The matrix of the glacial boulder beds is here a hard haematitic rock, and specular iron (a flaky form of haematite) occurs in holes in the rock. The glacial beds are about 100 feet thick in this area.

The beds associated with the glacial rocks here contain a very large amount of haematite, a mineral that is especially abundant in the Griqua Town beds in the west of Hay.

The brown and yellow banded magnetic jaspers form some prominent flat-topped hills on Kaffir Kop, Abel's Vlakte, Kopje and Vaal Water. They contain layers of silicified and oxidised crocidolite. As a whole, these beds lie at low angles, but there are sharp contortions in them. East of these hills there is much sand, through which the smaller hills that Stow called the Rooy Kopjes project. These are made of deep red jaspers, with black magnetic layers, and some whitish cherty rocks are interbedded with them. They are on the farms O. 72 (Kain's Vlakte), O.78, and O.86. The beds dip at about 5° towards S. 10°—20° E., *i.e.*, towards the Ongeluk volcanic series, but several hundred yards of sandy ground lie between them, covering up the glacial beds if these are present at their usual horizon.

(3.) *The Blink Klip Field Cornetcy and the Groen Water Area.*

In this part of the Division the Griqua Town beds occur as a wide anticline, which brings the Campbell Rand limestone to the surface in the greater part of the area. Near Groen Water the Griqua Town beds, consisting of yellow and brown magnetic rocks and the heavy blue rocks which contain crocidolite, dip south-eastwards away from the limestones and towards the Ongeluk series. The glacial conglomerate is exposed on the west side of M. 19, just west of the lowest volcanic outcrops.

On the west of the area the Griqua Town beds have a less simple boundary; in the north they dip under the Vlak Fontein volcanic syncline, reappear again only to dip under the overturned syncline (see fig. 3) on Lucas Dam. They are last seen in the remarkable ridge of yellowish, brown, and red jaspers and magnetite rocks, with interbedded limestones and white quartzites, which stretches from the Vryburg border to Floradale (O. 230), a distance of 16 miles in a straight line. This ridge is sharply defined and runs straight, and two southern inliers projecting through the gravel and sand on O. 229 show that it continues still further than Floradale. In this neighbourhood the sandy soil is thick, and conceals the rocks over many

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areas where the structure is doubtful, but on the east side of the ridge at Lucas Dam a chert boulder rock exists between the ridge and the volcanic rocks; the bed itself is not exposed, but typically striated stones were found along the strip of country where the rock should be. Their occurrence is of importance because the rocks in the ridge dip at a high angle towards W. 10° N., away from the volcanic beds on Lucas Dam, which very probably belong to the Ongeluk series. The western side of the syncline is thus inverted. The nature of the junction with the shales, quartzites, and conglomerates of the high ridge on the western boundary of the farm is doubtful. The Griqua Town beds dip under the latter, but the shales, conglomerates, and quartzites are not like any rock in the Griqua Town or

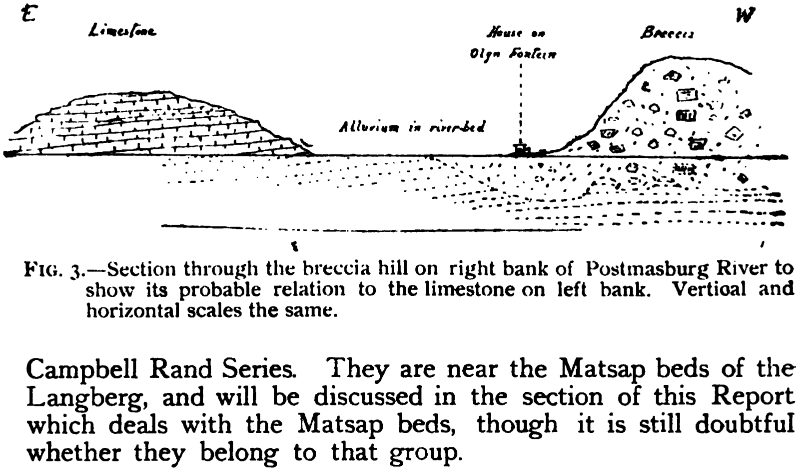

FIG. 3.—Section through the breccia hill on right bank of Postmasburg River to show its probable relation to the limestone on left bank. Vertical and horizontal scales the same.

Campbell Rand Series. They are near the Matsap beds of the Langberg, and will be discussed in the section of this Report which deals with the Matsap beds, though it is still doubtful whether they belong to that group.

The southern end of the broad limestone anticline must lie between Leeuw Fontein and Bonnet Fontein, but owing to gravels and tufaceous limestones, the outcrops are concealed to a great extent, and the single traverse I made through that area was not sufficient to determine the position of the boundary between the Campbell Rand and the Griqua Town series.

The top of the Griqua Town group is again seen on Sunnyside, M. 77. The glacial beds are well exposed there, and dip towards a small area of the Ongeluk volcanic series on the same farm. There is an interesting occurrence of pieces of chert with flat sides meeting at various angles in this outcrop of the glacial beds. These inclusions are embedded with the striated rocks in a hard brownish siliceous matrix, but they have only a few scratches on them, and the scratches are neither so long or so deep as those on the typical striated stones. In some cases the greater part of the surface of the fragment is formed by the flat faces, and in others only two or three flat

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faces are shown, the rest of the surface being irregular. The edges along which the flat faces meet are remarkably straight, a consequence of the flatness of the faces, which seems to me to be a very extraordinary feature. These stones look as if they came from a rock in which jointing was unusually well developed, but in a somewhat irregular manner, as two faces never appear to be parallel to one axis. Striated stones are quite as abundant in this locality as in any other visited.

The ridge which ends on Sunnyside is an anticline at the south end, but north of that farm the west limb alone remains, the east limb turns eastwards with south-easterly dip—but the connection with the Griqua Town beds on the east or left side of the Postmasburg river has not been made out.

Along the road from M. 93 to Lucas Dam a fairly continuous section through the Griqua Town beds, with the exception of the uppermost portion, can be made out, though the thicknesses assigned to the various groups of beds are not accurate, as no allowance could well be made for small faults and differences in dip, which are doubtless present. The section is as follows, in downward succession:—

	Feet.
Massive and thin bedded brown and yellowish jaspers, with layers very rich in magnetite...	700
Purple quartzites	50
Red and black ferruginous bedded rocks, softer than the jaspers	500
Greenish soapy quartz grit, like the steatitic rocks at Klip Fontein, 6 inches.	
Greenish quartzites, with occasional micaceous layers	300
Dark ferruginous rocks, with occasional layers of massive haematite	560
White quartzites	150
Ferruginous thin bedded rocks, red and black in colour...	780
Limestones (Campbell Rand group).	
	3,040 feet.

Parts of the section are concealed under sandy soil, and a stretch of sand quite a mile wide separates the westernmost outcrops of brown jaspers from the nearest volcanic rocks to the west. Though crocidolite and its altered forms were not seen on the line of section, they occur further south on the same hills.

The glacial beds crop out in a stream bed leading westwards from the Poort on Paling, and they are underlain by heavy blue-black rocks. They dip westwards at a rather high angle. The glacial boulder bed is softer here than elsewhere. The boulders are made of chert. This small area must be

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separated from the Matsap beds to the east by a fault, with downthrow to the east, and from the small patch of Campbell Rand limestone shown in fig. 5 by a second fault. The outcrops are too few to allow the structure to be ascertained definitely.

The Blink Klip Breccia.

This rock was described and given the above name by G. W. Stow.[1] Blink Klip is the old Dutch name (probably given by the Griquas) for a locality[2] near the village now called Postmasburg, from which the natives obtained red pigment. The red powder is specular iron in very small scales, and these give a glittering appearance to the rocks in the neighbourhood.

The rock is a breccia[3] of peculiar character; the fragments are sharp edged and of all sizes up to many yards, or even scores of yards in length, and the cement is siliceous or haematitic. The fragments consist of banded magnetic jaspers, usually coloured red with haematite, and cherts, just like the rocks which make up so large a part of the Griqua Town series; the blue heavy rocks which contain crocidolite have not been recorded from the breccia, nor have the altered forms of crocidolite. In many cases a rock consisting almost entirely of haematite shows on fresh surfaces the outlines and banding of fragments now converted into haematite. These outlines are barely visible, but on some weathered surfaces the original form of the fragments is more easily seen, owing to different rates of weathering along the variously arranged haematite crystals, and probably also owing to the presence of more silica in the fragments than in the matrix, or *vice versa*.

The specific gravity of a piece of the matrix, apparently free from large inclusions, is 5·17. No analyses have yet been made of these rocks, but they evidently contain much more iron than the usual ferruginous beds in the Griqua Town series, of which the specific gravity is about 3·4.

The chief mass of the Blink Klip breccias is that which forms the range of hills running north-north-east from Olyn Fontein, near Postmasburg, into the Vryburg Division; part of this range is called the Klip Fontein hills. Outlying masses occur on both sides of the main ridge, and on Paling there is another ridge, which must be continued into Vryburg. On Doorn Fontein there are at least two outliers, and a large mass occurs on Wolhaar's Kop.

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[1] Q. J. G. S., Vol. XXX., pp. 651-653.

[2] Called Sensavan formerly by the natives. See Burchell, I, p. 414 and II. pp. 255, and 258, 318.

[3] In "Die Kalahari" p. 633, Dr. Passarge suggests that the Blink Klip breccia is a surface debris formed and cemented together when the surface features were different from what they now are. This, however, is a quite impossible explanation, as the account of the breccia at Klip Fontein and at Wolhaars Kop will show.

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On the right side of the river at the south end of Postmasburg there is a hill made by breccias rising 150 feet above the river bed. The whole hill, which is about two miles long and a mile wide, seems to be made of fragments of red haematite and black magnetic jasper, with occasional layers of white and pink chert, cemented together by haematite and silica. In places there seems to be more matrix than fragments, in other places the fragments are merely huge blocks of banded rock shattered into innumerable pieces, hardly displaced from their original relative positions; the matrix fills the interstices, which may be mere cracks or may be a quarter of an inch wide. These great shattered blocks may have their laminae lying horizontal or nearly so, in conformity with the bed-planes of the neighbouring Campbell Rand limestone, or they may be in any other position. On the left bank of the river the Campbell Rand limestones crop out down to the river bed, and they have a slight dip to the east, so that the breccia is certainly at a lower level on the right bank than the limestone on the left; the river bed, about 100 yards wide, intervenes between the outcrops. The accompanying figure (fig. 4) shows the relationship of the two rocks so far as it is visible. Unfortunately the thick covering of sand on the west side of the hill prevents the section from being completed on that side, but flat outcrops of limestone occur between this hill and the south end of the greater ridge to the west. On the left bank the limestone is traversed by rather wide joints filled in with haematitic breccia, which can be followed for many yards across the veld. The breccia in these widened joints is like the less coarse parts of the breccia in the hill. The dotted lines in the figure below the level of the river bed will explain the way in which the breccia probably rests on the limestone. The hollow in the limestone occupied by the breccia certainly exists below the east side of the hill, but there is no evidence of its existence under the west side, for the sand conceals the outcrops there. It is possible, but not likely, that there is a fault with downthrow to the west on the eastern flank of the hill.

Two small outliers of the breccia near Postmasburg on the left bank of the river were noticed, and there must be many others not big enough to be seen from a distance.

The two outliers about three miles above the village on the right bank of the river are conspicuous hills, and they have very rugged outlines. At the base of the smaller hill, the one from which natives have obtained red paint from time immemorial, the limestone crops out within a few feet of the breccia, though a vertical section showing their relation is wanting. The limestone lies horizontally; on the east side of the valley, about 200 yards from the outcrop on the right bank, the limestone dips at a very low angle towards E. 10° S.

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The breccia on these hills is very similar to that described above from near Postmasburg. Its position relatively to the limestone is not quite so clearly seen, but the limestones of the left side of the valley would abut against the breccia if they were carried across the valley with the same dip.

The Klip Fontein hills are part of the western ridge of breccia which starts on Olyn Fontein; the outlines of the range are rough throughout, and parts stand out prominently, while close at hand there may be two or more deep cuts through the hills without any apparent connection with stream action. At Klip Fontein the hills are between 400 and 500 feet high. The kloof which opens out near the homestead affords a section along the axis of the range, and cliff sections on the outer sides, both east and west, are numerous.

The structure of these hills is very complicated, and to make a detailed map of two or three square miles would have taken more than a week. The whole mass, with the exception of a band of flaggy steatitic slates near the bottom of the kloof, is made of breccias like those described from Postmasburg, but cherts are rather more prominent at Klip Fontein, and there are many outcrops of black and white quartz rocks, which appear to be vein quartz filling irregular spaces and coloured with iron oxides. This quartz has a different appearance from the usual siliceous matrix; it is less chalcedonic, and more like ordinary vein quartz.

The individual fragments in the breccia increase in size, on the average, from the bottom of the hills upwards, and on the top one finds huge blocks, brecciated to a certain extent, and displaced from the horizontal, but arranged in a more or less orderly fashion. Between the blocks there is breccia of smaller-sized pieces. The

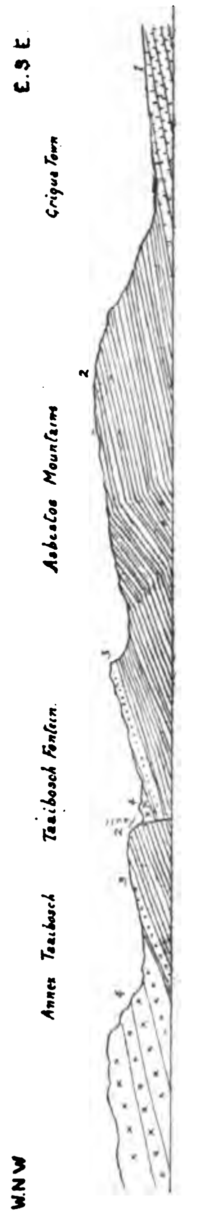

FIG. 4.—Section through the Asbestos Mountains near Griqua Town. Distance, 17 miles. Horizontal to vertical scale, 1:5. 1. Campbell Rand series. 2 and 3, Griqua Town series (3 is the glacial conglomerate). 4. Ongeluk volcanic series.

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blocks may reach a length of 100 yards or even more. On the nearly flat top of the Klip Fontein ridge on each side of the central kloof the great dislocated blocks dip at various angles towards an axis which coincides with the direction of the kloof, and at the top end of the kloof the blocks dip down towards it, while at the south end the peculiar steatitic slates dip up the kloof. The whole arrangement of the blocks gives one the impression that horizontal rocks were fractured and sank into an elongated hole, the interstices being subsequently filled up with haematite and silica.

The large blocks of banded rocks seen near the top of the hills are occasionally found to have their laminae contorted, but this is by no means usually the case. Generally, the rocks appear to have been broken without having been bent.

There is some steatitic mineral in layers closely associated with the jaspers in the Klip Fontein hills. There are also small irregularly shaped strings of a soapy substance in parts of the brecciated rocks. The steatitic slates mentioned previously are rather peculiar rocks; they have not been shattered to the same extent as the jaspers and cherts, but their general arrangement agrees with that of the larger blocks of the latter. The steatitic rocks have not yet been examined microscopically, for the sections are not at present available.

In connection with the Klip Fontein hills there is an interesting outcrop of a quartzitic rock, with small pebbles of chert, on the east side of the hills about three miles north of the homestead. The rock crops out close to the base of the hills, and dips towards them. It is interesting, because similar conglomerates have been described from the base of the Pretoria beds in the Marico district.[1]

The hills near the gap through which the road to Lucas Dam from Postmasburg passes are part of the same range as the Klip Fontein hills, and they are made of similar rocks. A small outcrop of limestone was met with in the middle of the gap. Some of the low lying breccia outcrops contain huge masses of contorted and broken banded rocks, now converted into haematite.

On Paling the Blink Klip breccias form a ridge which is continued into the Vryburg Division. Dolomitic limestone occurs on the flat ground between this ridge and the Klip Fontein hills; on its western side the breccia is overlain by the Matsap beds, which dip a few degrees north of west.

On Wolhaar's Kop the breccia appears in the axis of an anticline. On the west side the breccia passes into unbroken Griqua Town beds, which dip under the volcanic rocks of Floradale (O. 230), but the eastern limb has been denuded away near Wolhaar's Kop, though it is preserved on Sunnyside three and a half miles to the south, where the lower beds have been carried below the surface. The thickness of the breccia on Wolhaar's Kop must be more than 200 feet thick.

[1] Hatch, F. H., Trans. Geol. Soc. S. A., Vol. VII,, p. 1. Holmes, C. G., Trans. Geol. Soc. S.A., Vol. VIII., p. 167.

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There are low hills of the breccia on the Vryburg boundary line between Klip Fontein and Riet Fontein (Barkly West). Mount Huxley seems to be the name of a hill just across the Vryburg border, and not on it, as is stated on the 12·6 miles to the inch map of the Colony. In Stow's[1] section, Fig. 7., Pl. xxxix., the name is given to a hill between Blink Klip and Klip Fontein, though in his map, Pl. xxxiv., it is placed north-east of Klip Fontein.

Origin of the Breccia.

Stow[2] considered the breccia to be a detrital rock derived from the breaking up of the Griqua Town beds. This explanation is not acceptable. The character of the rock is quite different from that of a detrital breccia. The huge angular blocks, often shattered, but without dispersal of the fragments, lying amongst smaller angular fragments, are without parallel in an ordinary breccia. The arrangement of these great blocks on the top of the Klip Fontein hills is another obstacle, and so is the apparent absence of pieces of foreign rocks, such as granites and diabases. Then, again, on Wolhaar's Kop, the breccia is overlain by normal Griqua Town beds, into which it passes gradually, which negatives the supposition that the fragments in the breccia came from the Griqua Town beds by the ordinary processes of atmospheric denudation. The exclusively angular shape of the fragments is another difficulty.

It is clear that some other explanation must be found.

One obviously important fact is that in every locality where the breccia occurs it very probably lies upon the Campbell Rand limestones, *i.e.*, it replaces the lower part of the Griqua Town series by a mass of fragments of these same beds, re-cemented by iron ore and silica. This recalls the fact that the base of the Griqua Town beds near the village of Griqua Town are sharply contorted, and also the descriptions by Stow[3] of the hollows in the surface of the limestone at Ramaje's Kop, in which the lowest beds of the Griqua Town series are lying. Stow attributed the appearances at Ramaje's Kop to the unconformable position of the Griqua Town beds on the limestone and thrusting from the west during and after the deposition of the Griqua Town beds. No other evidence has been obtained for the existence of the unconformity, and there are obvious difficulties in the last part of the explanation.

If we suppose the limestone to have been dissolved away in certain areas after the Griqua Town beds had been laid down, probably after they had been converted into magnetic jaspers, much difficulty is removed. The brittle jaspery rocks sank irregularly into the cavities thus made, perhaps during a period of

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[1] Q. J. G. S., Vol. XXX.
[2] Q. J. G. S., XXX., p. 653.
[3] Q. J. G. S., XXX., p. 665.

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earth movements which started the collapse. Where great cavities existed great thicknesses of breccia were formed, but the brecciation became less upwards, so that unbroken Griqua Town beds lay upon the breccia. Where solution took place on a small scale only, we find crumpled strata at the bottom of the Griqua Town series, as near the village, overlain by beds not so disturbed.

The haematite and silica must have been introduced after the main part of the brecciation process had taken place .

The fact that the breccia crops out below the level of the limestones below Postmasburg is important, as showing that this mass of breccia may lie in a hollow dissolved in the limestone, but proof of such a position in the case of this and the other breccias has not yet been obtained. The filling up by breccia of irregularly widened joints in the limstone would be expected under the conditions supposed to have obtained during the formation of the breccia.

The greatest development of the breccia is along anticlinal axes, yet the unbroken rocks on the Wolhaar's Kop anticline do not dip towards the breccia. If the folding to which the anticlines are due also started the disruptive action this state of things can be understood. The slight divergence of dip between the limestones and the unbroken Griqua Town beds which would be expected on this hypothesis has not been noted, but its observation would in any case be a matter of difficulty. That the breccia is due to earth-movements in the ordinary sense is very improbable, for no sign of thrusting is observable in the localities where the breccia occurs, and this rock does not resemble any breccia known to me which is supposed to be due to that process.

A case of the collapse of Karroo beds into hollows dissolved out of dolomite near Pretoria is described by Molengraaff,[1] but but I have not met with a description of phenomena due to this process on such a large scale as is implied by the Blink Klip breccia of Hay.

THE ONGELUK VOLCANIC SERIES.

This group occupies a large part of Hay. Stow called them "Amygdaloidal and associated rocks of Pniel, Vetberg, etc.," on the map, pl. xxxv.[2] and "amygdaloidal rocks of Ongeluk and Moss Fontein," on p. 662 and elsewhere. He identified the Hay volcanic rocks with those of Pniel and the Vaal River valley (belonging to the Ventersdorp system of Hatch and the Vaal River system of Molengraaff), on account of their resemblance, but his sections show what difficulties this led to. Dunn placed both the Hay volcanic rocks and those along the Vaal River in

[1] Geology of the Transvaal, 1904, p. 78.
[2] Q. J. G. S., Vol. XXX.

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one group of "Diabase later than the Lydenburg beds,"[1] but he does not explain how the Vaal River rocks can be got into that stratigraphical position, nor, so far as I am aware, precisely what rocks are included by this term "Lydenburg beds."

There is no doubt that there are two great groups of volcanic rocks between the Vaal River and the Langeberg, one of which, the Pniel and Vetberg group of Stow, lies below the Campbell Rand limestones and in part, at least, below the quartzites, etc., under the limestones, and the other above the Griqua Town beds.

The Ongeluk series forms seven distinct areas in Hay; all of these are synclinal basins, and will be considered separately for convenience.

The rocks are lavas, breccias, fine-grained tuffs, and a few intercalated layers of brilliant red jaspers.

In the areas marked as covered with the Ongeluk series in the map accompanying this paper there are some masses of intrusive igneous rocks. The separation of these from the intrusive rocks presented such difficulty in the field that it was not attempted. A detailed survey, occupying a long time, would have been necessary to map out the breccias and tuffs as distinct from the lavas, for the two kinds of rock make very similar outcrops, and the finer grained lavas are difficult to distinguish in the field from some of the tuffs; this work, therefore, was left unfinished.

1. *The Ongeluk-Witwater Basin.*

This large synclinal area of volcanic rocks stretches from Melk Vley and Ganna Laagte, south of Witwater, to beyond the Barkly West boundary, north-east of Groen Water, a distance of over 63 miles, and from the west side of the Asbestos Mountains, north of Kievets Kloof, the average width is about 18 miles. Owing to the bend south of Postmasburg, the general direction of the synclinal axis is north-east.

Traverses from the sedimentary rocks of the Griqua Town series on to this syncline were made from the south (Claradale to Witwater; from the west (Eden to Poortje; Matsap to Ongeluk; Wolhaar's Kop to Bosch Poort; Postmasburg to Tiger Kloof); and from the east (near Taaibosch Fontein (see fig. 4), Moss Fontein, and the north-north-east along the boundary between the two as far as Peiser's mine).

In every case the Griqua Town rocks dip towards the volcanics, though there is at all the localities mentioned a strip of sand which covers the passage beds to a greater or less extent.

[1] Geological Sketch Map of South Africa, Melbourne, 1887. From the map itself "Lydenburg beds" include everything from the Campbell Rand to the Matsap series, excepting the Ongeluk beds.

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It is found that the lowest members of the volcanic group are especially liable to give rise to hollows, flat valleys, in which reddish sandy soil accumulates. The volcanic rocks usually rise as escarpments at a distance of from one to two miles from the uppermost beds of the Griqua Town series. The dips of the latter are rarely as much as 10°, and on reaching the volcanic beds their dips are usually found to be less, though from the nature of the lavas and tuffs it is not easy to observe the dip accurately. The lavas, etc., are thick bedded, and it is from the step-like declivities of the escarpments that their stratigraphical position is arrived at. This feature is well seen in the hills made of the volcanic rocks south-west of Peiser's mine as far as Smit's Dam (O. 3), on Melk Vley, Van Nel's Dam, and the hills stretching from Bosch Kloof north-eastwards to Tiger Kloof.

So far as the evidence yet obtained bears on the question, the Ongeluk volcanic series lies conformably upon the Griqua Town beds in Hay. This conclusion is based on the fact that wherever the rocks immediately below the volcanics are visible they are either the glacial beds or ferruginous rocks, cherts, and thin limestones, *i.e.*, beds known to belong to the uppermost part of the Griqua Town series. There are, of course, many tracts of country where the succession cannot be ascertained for want of outcrops, but the occurrence of the uppermost Griqua Town beds dipping towards the Ongeluk series was so frequently observed in the case not only of the Ongeluk-Witwater syncline, but in those of the six other synclines as well, that I have no doubt that the above conclusion is correct.

At one boundary only is there contradictory evidence, along the western side of the Lucas Dam syncline the uppermost Griqua Town beds are reversed, and they dip westwards away from the volcanics at a high angle. This is certainly an overturned succession due to folding subsequent to the out-pouring of the Ongeluk lavas, possibly, also, subsequent to the deposition of the Matsap beds.

From Stow's map[1] it would be thought that the volcanic beds lie against the Campbell Rand limestones between Gasip and Ongeluk, but this is not the case; the volcanic rocks are nearly 20 miles wide across their strike near Gasip, and they extend many miles north of that place. Stow evidently went round the north end of the syncline without knowing that the volcanic rocks existed so far north as Tiger Kloof. From the hill-tops at Tiger Kop, Groen Water, and north-east of Peiser's mine I saw a ridge, which is evidently continuous with the hills made of the Griqua Town series on Doorn Fontein (Barkly West), stretching round to join the Asbestos Mountains somewhere north-east of Vogelstruis Dam, but I could not locate the ridge on the map, and that part of the country has not yet been examined.

[1] Stow, *loc. cit.*. Pl. XXXV.

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The lavas in the Ongeluk syncline are chiefly compact, fine-grained, blue-green rocks, in which one can make out little or no structure in the hand-specimen; small black flecks, which are often seen, resemble the flecks in the lavas of the Juanana syncline described below, and are doubtless the same mineral, bastite pseudomorphs after enstatite. More obviously crystalline lavas occur in the Ongeluk hills and south of Tiger Kop.

Amygdaloidal lavas are seldom met with in the Ongeluk syncline; the only places at which I saw outcrops of this type were on O. 78 (near Waterboer's Dam), on Vlak Plaats and Blauwbosch Kuil, and Kruger's Dam.

Breccias occur more frequently than amygdaloids; they are bluish-green or pale greenish grey rocks, with angular pieces of compact lava in them. The pale green rocks probably owe their colour to epidote, a decomposition product of certain minerals in the lava fragments and the comminuted lava of the matrix. Outcrops of breccia were seen on Kruger's Dam, Ongeluk, at several places between Waterboer's Dam and the western border of the syncline, on Blauwbosch Kuil and Vlak Plaats, and on Bosch Poort.

There are many outcrops of compact rocks which show no sign of crystalline structure, and which are probably fine-grained tuffs. These have not yet been examined under the microscope, nor have the lavas of the Ongeluk syncline.

The breccias and tuff-like rocks are not confined to any one horizon in the series. Those on the west side of Waterboer's Dam are near the base, and those on Ongeluk must be high up in the group.

A very remarkable rock is the brilliant red jasper which occurs in beds intercalated with the lavas from Van Nel's Dam through Waterboer's Dam, Kain's Vlakte, and Bonnet Fontein to Sunnyside. This rock is rarely seen in outcrops, though fragments of it are found in gravels in very many parts of Hay, and also east of the district. There is no jasper in the Griqua Town series known to me which has such a brilliant colour. It is unfortunately a brittle rock, though very hard, or it would be of use as an ornamental stone. Along certain lines of country, one of which has been stated above, while another runs from Taaibosch Draai, below the escarpment east of Ongeluk and past Peiser's Mine, pieces of this jasper are seen on the veld more frequently than elsewhere, and approximately mark the position of the rock below the soil.

On Waterboer's Dam the red jasper has been opened up by cuttings; it is interbedded with greenish chert and a diabasic rock. At this locality there is a fault on the west side of the jasper opened up, and the latter has an almost vertical dip. One outcrop strikes E. 15° N., quite an abnormal direction for this area, and is isolated from others to the north and south by faults.

Thin sections of this jasper are not yet available.

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It appears to represent a deposit laid down on a floor of lava and covered by later flows of lava.

As mentioned previously, there are rocks associated with the Ongeluk volcanic series that are probably intrusive. A mass of probably holocrystalline diabase occupies a wide area on the east side of the volcanic rocks between Taaibosch Puts and Moss Fontein. In this mass is situated the dyke-like body of basic breccia from which diamonds are obtained at Peiser's Mine. The excavations at the mine are the only places where one can get a good section through the diabase, which is exposed for rather over 60 feet. Though much decomposed within 30 feet or so of the breccia, the rock is well enough preserved to allow one to ascertain that there are no divisional plains within the exposed thickness to represent surfaces between successive flows of lava. Fresh rock from the same mass was got from a well further from the breccia, but it has not yet been examined in thin section.

From the facts known at present, it is impossible to be certain of the nature of this diabase, though the appearance of the rock in the mine cuttings inclines me to the opinion that it is intrusive.

A tongue of probably similar rock lies east of the fault on Taaibosch Fontein. From the field evidence, this rock may be either a lava flow or an intrusion; I could not decide the point.

The only rocks from this great syncline that have yet been cut for microscopic examination are two varieties of diabase from Witwater. In one of these (1,448) there is much colourless augite in elongated sections, often twinned once along the orthopinacoid and having many lines of dusty inclusions parallel to the base; the augite is partly changed to chlorite; it occasionally encloses parts of the ground mass, but typical ophitic structure is not seen. The felspar has almost entirely suffered change into aggregates of other minerals, amongst which epidote, chlorite, quartz, and colourless hornblende are recognisable. There may be patches of felspar left amongst these aggregates, but they do not show twinning. No calcite is seen amongst the alteration products. There is a fair amount of original quartz present, some of it intergrown with what was once felspar. Leucoxene and iron ores are present in small amount. The original nature of the ground mass in this rock is obliterated, but it is probable that the rock was not holocrystalline, in the sense that a typical dolerite of the Karroo region is. Another section (1,447), taken from a green rock, is still further altered; the most conspicuous constituent is epidote; augite is represented by a few small remnants, the most of it has changed, apparently into epidote. There is much quartz and felspar in the ground mass in irregular patches of which the boundaries do not coincide with the outlines of the original felspars, as indicated by streaks of dusty inclusions. There is more leucoxene in this rock than in the last.

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The maximum thickness of the volcanic rocks in the great syncline must be very considerable, probably over 1,000 feet; but the difficulty of getting a series of observations for dip makes an approach to exactness impossible. It is likely, also, that there are several strike faults within the area corresponding to the Taaibosch fault. One such fault brings in a considerable thickness of the Griqua Town beds on Waterboer's Dam and Lake Warren; the thin limestones, ferruginous rocks, and cherts are exposed, but the glacial conglomerate was not seen; it is probably under the sand on the west side of the ridge.

2. *The Juanana Syncline.*

This is a much smaller area of volcanic rocks, but in many respects its small size is compensated by other points of interest, the clear evidence of its relation to the Griqua Town series and the repeated intercalation of breccias and tuffs with the lavas. The length of the syncline is about eight miles, and its greatest width little over three.

The north end of the syncline is a great rounded mass, which rises to form a high hill, on which is placed the beacon common to Kama, Omdraai, and Juanana. The highest sedimentary rocks which I saw on approaching the hill from the east are hard reddish jaspery rocks, interbedded with heavy blue slates; a considerable interval of covered ground comes between these outcrops and the lowest of the volcanic group, which is a very compact blue-green rock, with black flecks in it; the black flecks are rarely a millimeter in length. Under the microscope, the black spots are seen to be enstatite crystals or pseudomorphs after that mineral, and the ground mass (1,442) is made of feathery aggregates of a fibrous mineral, very pale green, non-pleochroic, and usually with an extinction angle of several degrees off the length of the fibres; it gives yellowish-white tints between crossed Nicols; it seems to be more like an amphibole than any other rock-forming mineral known to me. No felspar laths nor any indication of them are visible. In amongst the feathery hornblende there is some quartz, in the form of a minute mosaic. Very small grains of epidote are also present, and in one spot this mineral has taken the place of an enstatite crystal. This rock is evidently a variety of enstatite-andesite.

Further up the hill there are grey and green compact rocks, showing no structure to the naked eye. A section through one of these (1,443) shows a very fine-grained material, in which quartz, in the form of mosaic, is the most important constituent, but with the quartz there are immense numbers of very minute, more highly refracting yellowish grains and short needles. These are too small to identify. The rock is probably an altered fine-grained tuff.

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The top of the hill is made of a bluish rock (1,444), which is less compact than the lowest lava. Under the microscope, it is seen to consist of a greatly altered ground mass, in which there are small porphyritic crystals of two kinds; one is augite in long and irregularly bounded prisms, and the other was in shorter prisms, with straighter boundaries; but it is now represented by pseudomorphs of a serpentinous mineral; the shape of the cross sections of the latter is that of the pyroxenes, and they were probably enstatite. There is still some felspar in small laths, partly decomposed. The bulk of the ground mass is made of very minute areas of more or less clear minerals, and appears to be isotropic under a low power, but under an eighth-inch objective, it splits up into the small areas mentioned.

This rock is a pyroxene-andesite, and from the appearance of rocks from other localities, it is probably a common type of lava in the Ongeluk series.

The compact green rocks with small enstatite crystals are also very widely spread in this series.

The south-western beacon of Juanana is placed on the top of another hill of lavas and tuffs. From a distance of two or three miles, the synclinal structure of this hill is very obvious; the upper beds of the Griqua Town series are seen to dip under the lavas on either side and the differences between successive lavas and tuffs or breccias is brought out by the weather, so that the hill sides show several step-like outcrops of the harder layers. The best section is afforded by the eastern slope of the hill; there the glacial beds are separated from the lowest lava flow by thin bedded reddish brown argillaceous quartzites and a spotted rock of more or less the same nature, about 30 feet thick in all. Above this quartzitic rock there lie about 500 feet of volcanic beds, as follows:—

Lava, compact enstatite-andesite	100 feet.
Coarser lava	40 „
Rather coarse breccia	15 „
Coarse lava	20 „
Breccia	25 „
Compact enstatite-andesite	80 „
Fine grained blue argillaceous rocks, probably tuffs	30 „
Lavas (1,454)	120 „
Compact enstatite-andesites	100 „
Reddish brown quartzites, etc., 30 ft. Glacial conglomerate	—
	530 feet.

A section (1454) of a rather blotchy looking compact blue lava, about 200 feet above the base of the series, shows altered crystals of a pyroxene set in a matrix that was once glassy, and

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which contains long laths of felspar, replaced by a quartz mosaic and other transparent minerals, and accompanied by long feathery growths of colourless hornblende. The rock was evidently of the same type as that from which section No. 1,442 was taken, but the remains of a glass base are more abundant and the former presence of felspar is more distinct. The pseudomorphs after the pyroxene are either serpentine, quartz, or partly made of each of these minerals. The original nature of the crystals is evident from the characteristic shapes of the transverse sections.

No amygdaloid was seen in place, but the frequency of large fragments of the rock along parts of the slopes proves its existence. A section (1,455) from one of these fragments shows a large amount of augite, partly fresh, but mostly altered to a greenish granular substance, lying in a quartz and perhaps felspar ground mass; much of the greenish substance looks like chalcedonic silica coloured by chlorite.

There is much sphene in small grains in this rock. Chalcedony, calcite, and a chloritic mineral occur in the amygdales.

On the south-east side of the syncline there is a fault which repeats the bottom of the volcanic group and the top of the Griqua Town series. It is very similar to the Taaibosch fault, and has the downthrow side on the east.

No outcrops of the bright red jasper were seen in the Juanana syncline, but on the eastern side, about two miles from the south end, there is a group of cherts, a few feet thick, in the lavas. A thin section of this chert shows that there also are small patches of calcite and small flecks of a chloritic mineral. The rock in situ has the appearance of having been interbedded with the lavas during their formation, and the characters seen under the microscope are consistent with this view, for it does not appear to be a silicified tuff or other rock of volcanic origin.

3. *The Abram's Dam Syncline.*

The whole of this syncline has not been examined, and its northern and southern limits are at present unknown; its length from N.N.E. to S.S.W. is certainly over 16 miles, and its width, from Waterkop to Middel Kop, about 11 miles. The eastern limb of the syncline forms a well marked escarpment, visible from a long distance, and distinguishable from the hills of Griqua Town beds to the east by its colour and shape.

At the base of the series on the farms from Koodoos Dell to Namiecaap there are compact lavas, below which the highest visible rocks of the Griqua Town series are ferruginous beds, with cherts and limestones. A well-marked line of valleys on Eland, Stinkwater, Abram's Dam, and Namiecaap, running parallel with the strike of the beds, is caused by the presence of a rather thick belt of flaggy green tuffs, which weather more

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readily than the lavas above and below; they dip westwards at a low angle. West of these green flaggy beds there is a considerable thickness of lava, probably some 300 feet, below a thick belt of volcanic breccia on the farm Klip Bak. For some five miles westwards from these breccias the country is covered with deep sand, but there is a slight ridge of lava on the farms Zwart Veld and Naauwkop, a few miles south of the road. The beds in the middle of the syncline lie at very low angles, as can be seen on the Klip Bak outcrops. Towards the west side of Middel Kop and Zwart Veld the breccias are again seen, greenish, coarse rocks, with angular fragments of lava, like the Klip Bak outcrops; they are underlaid by a thin band of compact lavas, which rest upon the Griqua Town beds; the uppermost outcrops of the latter are again ferruginous cherty rocks, with limestone beds.

No microscopical work has been done on the rocks of the Abram's Dam syncline, but the lavas and breccias are evidently of the same general type as those in the Ongeluk and Juanana synclines.

4. *The Paarde Vley Syncline.*

This volcanic area is separated from Abraham's Dam syncline by an anticline of Griqua Town beds. It is about nine miles long and three wide at the broadest part. The angles of dip at the periphery are rather higher than those round the other synclines. The greater part of this area is made of compact blue lavas, with the small dark crystals of enstatite or minerals which replace it; on the north of Koegas Puts there is a large mass of breccia, apparently lying above the highest exposed lavas.

5. *The Leelyks Dam Syncline.*

This comprises a small area of volcanic rocks on Leelyks Dam, Kwakwas, Gras Gat, and Witberg. It is composed of lavas, amygdaloidal and compact, and breccias. A thin section through a breccia (1460) from this area shows it to be made of fragments of vesicular lava set in a matrix which contains epidote and much quartz. One lava fragment is a rock made up chiefly of small felspar laths belonging to the oligoclase-andesine group, set in an indeterminate base; there is no visible ferromagnesian constitutent in this fragment, which differs considerably from the few lavas of this group that have been examined in thin section.

The north end of this syncline is probably concealed under the sand east of Piljaar's Poort. Round the east, south, and south-west sides the Griqua Town beds dip under it; on the west side it is bounded by the ridge of Matsap beds which runs

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south-south-west through Piljaar's Poort. I did not find a clear section through the junction of the two rocks, but the general course of the boundary, taken together with the higher position and westward dip of the Matsap bed, left no doubt in my mind that the latter lie unconformably upon the volcanic beds.

6. *The Lucas Dam Syncline.*

There is an area of volcanic rocks which stretches from Floradale past Lucas Dam into the Vryburg Division, and it is certainly more than 20 miles long. The ridge on which Wolhaar's Kop stands is made of Griqua Town beds, dipping, on the western side, towards the volcanic rocks; and in the long ridge of the upper part of the Griqua Town beds on the west side of the volcanic rocks the former dip away from the latter, so the western side is overturned.

The volcanic rocks themselves make but few outcrops from Lucas Dam southwards, but all the wells, of which there are three known to me, in that distance of about fifteen miles, reveal the presence of the lavas under the soil, and at Floradale and Lucas Dam outcrops are met with. About five miles north of Lucas Dam the volcanic rocks rise into a hill of same general appearance as those in the Juanana syncline. An inlier of the Griqua Town beds, faulted on the east against lavas (which are on the downthrow side), occurs on Lucas Dam.

It is possible that this area of lavas may be directly connected with the Ongeluk-Witwater syncline by the north-westward projection of the latter on the farm Sunnyside; but direct evidence of this is wanting. There may also be a connection, concealed by the soil, between the volcanic rocks just north of Lucas Dam and the Vlak Fontein syncline.

7. *The Vlak Fontein Syncline.*

This is the south end of a larger area in the Vryburg Division. It is partly, at least, separated from the volcanic hills north of Lucas Dam by an anticline of the Griqua Town beds, while to the east there is the faulted country near Paling ridge (see fig. 5). The effect of the faults is to bring the Campbell Rand limestone nearer the volcanic rocks on the surface than they would be if the district were free from faults. The intervening ground, so far as two traverses gave evidence, shows no outcrops from beneath the sand and calcareous tufa over a width of nearly two miles.

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Comparison with the Pniel Volcanic Rocks.

There is as yet insufficient material on which to base a satisfactory comparison with the volcanic rocks below the Campbell Rand limestone and the Black Reef. In the field there is often a considerable resemblance between them, but so far as the present survey has gone the more acid rocks which occur abundantly in the Pniel series at Villet's Kuil, Bidouw's Kuil, and T'Kuip, and also in the Pniel and Kimberley area, are not matched by similar lavas and breccias in the Ongeluk group; this is especially the case with the acid porphyries which are conspicuously developed along the Brak River (Hope Town), and have not been met with in the Hay Division.

Amygdaloidal lavas are much more abundant in the Pniel group than in the Ongeluk.

Hitherto the only interbedded fragmental rocks noticed amongst the Ongeluk lavas have been breccias, green tuffs, cherts and bright red jasper. No cherts or jaspers have been recorded from the Pniel group,[1] but in the Kimberley shafts thick quartzites and shales are certainly interbedded with the igneous rocks.

Inter-relation of the Synclines in Hay.

From the general similarity of their contents and the high scarped edges of synclines, it would be gathered that the Ongeluk volcanic rocks once formed a continuous area, covering a very large part of the Hay Division.

At present there is no definite evidence of the position of large vents

[1] Cherts have been found in the Zoetlief beds of Vryburg, which probably belong to the Ventersdorp beds, the group that also probably includes the Pniel lavas and breccias. See Du Toit, below.

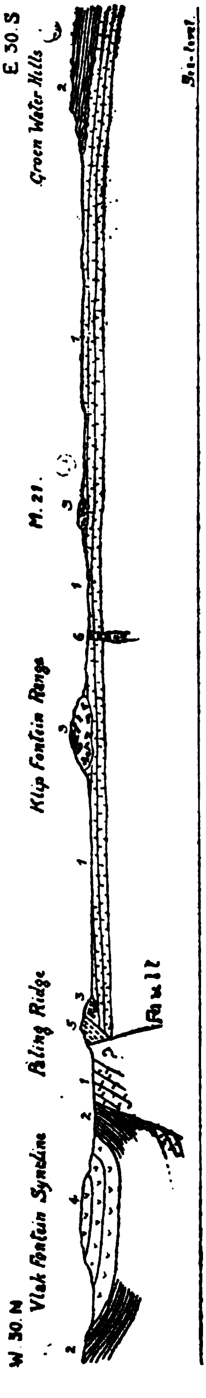

FIG. 5.—Section through Blink Klip Field Cornetcy. 1. Campbell Rand series. 2. Griqua Town series. 3. Blink Klip Breccia. 4. Ongeluk volcanic series. 5. Matsap beds. 6. Dolerite or diabase dyke. Distance, 19½ miles; horizontal to vertical scale, 1:2.

from which the lavas and breccias were ejected. While traversing an area of coarse breccia on Klip Brak and another on Leelyks Dam, I thought that these breccias might be the contents of a throat, but at Klip Bak there were signs of stratification. A much more detailed survey than I could make last season will be necessary to find out the probable sources of the lavas and breccias.

Under the heading of "Intrusions" there will be found an account of some masses of diabase, which present some resemblance to the coarser varieties of the Ongeluk lavas, but which are intrusive amongst the surrounding rocks. Some of these may have been formed in connection with the volcanic activity during the Ongeluk period.

THE MATSAP SERIES.[1]

The Matsap beds form three distinct groups of ridges in the Hay Division, of which the Langebergen are the most important.

This series consists of quartzites and grits, with occasional thin layers of conglomerate. There is one area of a peculiar ferruginous conglomerate in the Matsap ridge. The general colour of the rocks is purplish grey, and in their typical form they are distinguishable from all other quartzitic rocks known to me from Cape Colony. Associated with the typical Matsap beds of the Langeberg there are others, whose relation to the rest of the formations is still a matter of doubt, but as they are so closely connected with the Langeberg, I have marked them on the map published with this Report with the same stippling as the Matsap beds, and their relations are discussed below.

The three groups of hills formed by the Matsap beds are:— (1) The Matsap ridge; (2) The Langebergen, etc.; (3) The Paling hills.

1. *The Matsap Ridge.*

This range of hills made of the Matsap beds is about fourteen miles long, and at the most rather over two wide. It is cut through by the dry river bed near Matsap, and again by the dry channel on Zaai Plaats.

It is only at the extreme south end of the ridge that the relation of the rocks to other formations can be made out. The beacon common to Paauw Vley, Cairn Toul, Nek, and Koodoos Kloof stands on the top of the south end at a height of 500 feet above the flat ground on Nek and Koodoos Kloof. The Matsap grits and quartzites form the uppermost 200 feet or so of the hill, while below them massive haematitic rocks, passing below

[1] Dr. Siegfried Passarge uses the term "Langeberg beds" ("Kalahari," 1904, p. 70) in place of "Matsap beds" on account of the great importance of the Langeberg range as a feature in the land, but there is insufficient reason to change the name, and in view of the existence of several ranges called "Langeberg" in different parts of the Colony that term is a bad one

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into banded white and red cherts and belonging to the upper part of the Griqua Town beds, crop out round the west, south, and east sides of the hill. The actual junction is hidden under fallen debris, but the low dips of the Matsap beds towards the axis of the ridge on either side, for at least four miles north of the south end, show that the southern part of the ridge is a syncline of Matsap beds resting upon haematitic rocks of the Griqua Town series. These haematite rocks lie just below the glacial conglomerates on the central part of Koodoos Kloof and on Water Kloof. North of Lang Kloof the structural features cannot be made out so well, because on each side of the ridge sand and alluvium cover the rocks completely for a considerable distance from the Matsap outcrops.

On Zaai Plaats the synclinal dips are seen, but the beds are considerably bent, so that the ridge is no longer a simple syncline.

On the south end of Cone and on the east side of the ridge there is a small "hoek," formed by a subsidiary anticline in the Matsap beds, through which the haematitic beds of the Griqua Town series protrude, owing to the denudation of the crest of the anticline.

At Matsap itself the exposed part of the ridge is an anticline. The sections along the sides of the poort show the rocks dipping towards E. 40° S. at about 40° on the east side; further north they dip in the more usual direction of E. 20° S. an angles of about 70°; on the western side of the ridge the dips are less clearly seen, but they are towards W.N.W. at lower angles than the eastern dips.

The north end of the ridge slopes down under the great alluvial flats on O. 81.

The bulk of the Matsap beds of this area are purplish quartzites and grits, containing pebbles in thin layers or scattered through the rock at wide intervals. The pebbles are of white quartz, black and red jaspery magnetic rocks, and brown jaspers, but the brown jasper pebbles are not as often seen as the red. About a mile and a half north of the poort a prospecting shaft has been sunk on a bed of quartzitic conglomerate containing pyrites. The pebbles in this rock are quartz and quartzite, and black and red jaspery rocks. The results were apparently unfavourable. The superficial resemblance to some of the gold-bearing conglomerate of the Rand evidently led to the prospecting.

On the south side of the poort near Matsap there is a remarkable conglomerate exposed along the axis of the denuded anticline near the middle of the ridge. The matrix of the conglomerate is a very ferruginous reddish, fine-grained rock, which weathers with a brown coat; the pebbles are of all sizes up to

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12 inches in length; they are mostly well rounded, water-worn pieces of red and brown magnetic jaspers of the types so common in the Griqua Town beds of Hay. The conglomerate is roughly bedded, and evidently lies conformably below the purple quartzitic beds which are exposed on the east, south, and west sides of the area occupied by it. The rock immediately below the ferruginous conglomerate is not seen. The whole thickness of ferruginous conglomerate exposed is about 15 feet. Nothing like this conglomerate has been noticed elsewhere in the Hay Division; in the Langebergen and the Paling ridge no rocks with a highly ferruginous matrix was seen; these two groups of hills are made of precisely the same type of quartzite and grit, with pebbles of quartz and jasper, as are found in the Matsap beds.

The wells dug in the flat ground east of the Matsap ridge do not reach bed-rock, so the distance through which the Matsap beds extend towards the east is unknown; the nearest outcrops of the Griqua Town beds are about three miles distant.

2. *The Langebergen.*

Under this term I include all the ridges made chiefly of purplish quartzites stretching in a north-north-easterly direction from the neighbourhood of the Orange River below Pypwater to Andries Fontein and the Vryburg border, a distance of about 80 miles; they extend beyond the border for a considerable distance.

The direction of the strike of the beds varies; near the Orange River it is about N. 28° E., northwards from Baken Kop it is N. 24° E., while north of Paarde Kloof the strike in the main range is about N. 16° E., and that of the subsidiary ranges to the east, made of rock of which the relations are not yet satisfactorily determined, is near N. 5° E. It is interesting to note that the strike of the Ezel Rand beds (also of Matsap age) south of the Orange River in Prieska is on the average N. 35° E. I was unfortunately unable to complete the examination of the ground between Ezel Rand and Zeekoe Baarts Nek (O. 307), an area which will be surveyed this year (1906).

It was only at the extreme south end of the Piljaar's Poort hills that I found exposures of the Griqua Town or other beds at the base of the hills made of the Matsap beds. The Piljaar's Poort hills bifurcate on the western farm of the two called Witberg; the structure of the hills is there clearly synclinal, closely resembling the south end of the Matsap ridge. On the eastern side of the hills on Witberg the Matsap beds rest upon the Ongeluk volcanic series of the Leelyks Dam syncline.

On the small hill bearing the beacon common to Piljaar's Poort, Witberg, and Stilverlaats, the Matsap beds are in contact with the Griqua Town beds along a line of fault. The

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haematitic rocks of the latter series dip at high angles westwards, and the Matsap beds are highly inclined towards the east. The Matsap beds are purplish quartzites, with many pebbles, amongst which red and black banded jaspers are the most conspicuous.

A dry river bed, called the Matsap Loop, divides the Langeberg proper from the hills made of the same rock to the south. North of the Loop the Langeberg summits reach a height of about 1,600 feet above the flats, to the east of them, and usually there is a smaller difference of level above the Kalahari surface to the west. As Stow pointed out, the contours of the Langebergen are rounded, north of the Pad Kloof Pass there are considerable stretches of level ground on the top; but there are nowhere peaked summits on the main range. In contrast to this range, the eastern ranges, between Andries Fontein and Dunmurray on the west and Lucas Dam on the east, have some sharp peaks on them, probably due to the presence of thick shaly bands between the quartzites.

In the neighbourhood of Bakens Kop at the south end of the main range the rocks are thrown into two chief anticlines and two synclines; the dips are usually above 40°.

The Pad Kloof Pass affords a good section, and here the beds are much folded; on the eastern side of the range the dips are towards north of west at every place where the observation was made between the extreme south on Witberg and the Andries Fontein beacon hill; but in the western half of the range there are many curves, bold rounded troughs, and arches of a very different character from the sharp, but small bends in the Griqua Town series to the east. At one place on a hillside about a mile north of the west entrance to Pad Kloof there is a syncline with both limbs inclined eastwards. The figure in Stow's paper[1] gives a correct impression of the type of folding in the Langeberg, but the quartzites are carried too far eastwards towards Potgieter's.

A striking feature in the Langeberg is the uniform character of the rock; at places slightly sericitic beds are seen, and at others the rock is rather more deeply weathered than usual, but one finds the same kind of purplish gritty, coarse quartzites, with jasper and quartz pebbles throughout.

The eastern hills, made of rocks whose relations are doubtful, extend from the east side of Bergenaar's Pad to the Vryburg border, a distance of 20 miles. They form three distinct ranges, in all of which the beds dip at a very high angle towards the west; in the easternmost ridge there are some sharp contortions, but these do not materially affect the general statement. Unlike the typical Matsap beds, these rocks include several thick bands of micaceous brown shaly rocks, and there are at least two rather persistent beds of conglomerate in them, which do not

[1] Stow, Q. J. G. S. XXX. Pl. XXXIX. fig. 5.

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contain jasper pebbles. These conglomerates have been prospected for gold, but the results have not been made known. They are quartzitic rocks, with quartz pebbles and some pyrites in the matrix; the pebbles are abundant, well rounded, and reach a length of four inches; the thickness of the exposed bed of conglomerate is about two feet. The absence of jasper pebbles from these eastern rocks perhaps gives one a biassed opinion as to their relation to the Matsap beds, and the absence may be merely due to lack of observations, for I found a small piece of quartzite with a jasper pebble in it near the path across the boundary ridge on Lucas Dam; it was a loose piece, and may have got there accidentally. On the east of these ridges, between them and the Griqua Town ridge on Lucas Dam, there is a sandy valley in which there are shallow holes in the underlying rock, a purple talcose slate, unlike any other rock in the district. There may possible be an overthrust fault along the eastern side of the quartzite and shale ridges; the Griqua Town and Ongeluk beds are certainly overfolded towards the west in the immediate neighbourhood; but more work must be done in this region before a useful opinion as to the relation of the quartzite, conglomerates and shales can be given. In colour much of the quartzite is purple, like the usual Matsap beds, but grey, reddish, and brown rocks are not uncommon.

3. *The Paling Ridge.*

This is a ridge made of Matsap beds dipping about N. 20° W. at various angles from 10° to 40°, but the trend of the ridge is nearly north and south, and is determined by the course of the fault on its western side, along which the Matsap beds are thrown down against the Campbell Rand beds on the south and the top of the Griqua Town beds further north. The rocks are purple quartzites and grits, containing bits of brown and red jasper. They rest unconformably upon the Blink Klip breccias on their eastern side. These hills are continued into Vryburg.

Some of the Matsap beds on this ridge make good flagstones, which are used in the farmhouses in the neighbourhood.

General Relations of the Matsap Series.

The evidence afforded by the position of these beds at the south end of the Matsap ridge and at the south end of the Piljaar's Poort ridge is a strong confirmation of the view adopted in 1899 that the Matsap beds of Ezel Rand are later than the Griqua Town series; but we have also to say now that they are later than the Ongeluk volcanic beds. From the main ridge of the Langebergen no such direct evidence is as yet known.

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Then, again, we have the fact that pieces of red and brown jasper, supposed to have come from the Griqua Town beds, occur in the Matsap beds. These pebbles have not yet been examined microscopically, so their origin cannot be discussed with good effect at present, but it should be noted that jaspers and magnetic rocks occur in two formations in South Africa older than the Griqua Town beds, the Witwatersrand beds and the still older schists of Swaziland and of the Vryburg and Mafeking Divisions. This question of the origin of the jasper pebbles was very forcibly put before me during the field-work of last year by the fact that although the thick Ongeluk volcanic series is undoubtedly of later age than the Griqua Town beds, and, if the still later age of the Matsap beds be a true inference, although the volcanic rocks must have occupied a wider area during Matsap times than they do to-day, not a single pebble or other fragment of the lavas or breccias could be found in the Matsap beds. Now, considering that these volcanic rocks, apparently suitable for the supply of pebbles, as the Dwyka and recent gravels prove, did not contribute towards the material which went to form the Matsap beds in Hay, how could the underlying Griqua Town beds in that district do so?

A thin section (1461) of a grit from the Matsap beds at Piljaar's Poort shows that the grains of quartz are remarkably round in section. Their outlines are clearly indicated by films of dusty matter, and the interstices are filled with quartz.

As to the correlation of the Matsap beds with rocks in other parts of South Africa, I have no new information of importance. It has been suggested that they are not only the equivalents of the Waterberg sandstones of the Transvaal, but also of the Table Mountain sandstone of the south of Cape Colony and Natal.[1] Until palæontological evidence is obtained, objections to this view, that great disturbances and denudation must have gone on in the north during Bokkeveld-Witteberg times, and that during this interval the Matsap beds must have been converted into quartzites and closely folded, though under circumstances which exclude any but the thinnest cover, seem to me more weighty than the doubtful advantage of an uncertain correlation.

THE DWYKA SERIES.

These rocks occupy a very small part of our district. In the tongue of land enclosed by the bend of the Orange River near Prieska village there is a continuation of the large area of Dwyka beds which lies south and east of the village. The beds are boulder-beds of the nature of till, thin conglomerates and shales. Their presence is indicated by the numerous boulders

[1] Passarge, "Die Kalahari," 1904, p. 70. Hatch and Corstorphine, "Geology of South Africa," 1905, p. 309. Passarge correlates them, in preference, with the Cango and Ibiquas conglomerates.

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of various kinds of rock, often flattened and striated on one or more sides, which lie in the surface soil. Actual exposures are only seen in some of the ravines and are small, but looking eastwards from the Krantz Fontein hills I could see fine cliffs cut in the Dwyka beds further up the river than my work was carried. A ridge of Griqua Town beds projects through the Dwyka on Fonteinje and Spitzkop, and a small hill of the same formation does so on the outspan (Stof Bakkies). The Dwyka here fills up an old strike valley in the Griqua Town beds, and the modern drainage lines traverse the old valley nearly at right angles.

There is an outlier of the Dwyka on the limestones of Enkelde Wilgeboom.

The most abundant rocks in the form of boulders in the till and conglomerates are lavas, compact and amygdaloidal; they are mostly from the Pniel volcanic group; after these limestones or dolomites from the Campbell Rand and various rocks from the Griqua Town beds are most frequently seen; granites and gneiss are not uncommon.

No striated floors were observed in this area.

An interesting outlier of Dwyka was found on the farm Piljaar's Poort in the bifurcated end of one of the Langeberg group of hills. It appears to lie in a rock-basin, though there may possibly be a connection under the sand westwards with a larger area of Dwyka along the Orange River, but none has been noticed there as yet. If the hollow is a true rock-basin it will be very difficult or impossible to determine its nature or origin, for the rocks are not well exposed. A well about 60 feet deep has been sunk in the outlier without reaching the bottom. The matrix of the Dwyka is a gravelly grit; no mudstone was passed through in the well. The boulders have the characteric shapes and striations; the most abundant rocks are Matsap quartzites, jaspers, etc., from the Griqua Town beds, volcanic rocks, both lavas and breccias, felspar porphyries, and more basic igneous rocks, which probably came from dykes or other intrusions.

On the eastern side of the Campbell Rand, below the escarpment, the Dwyka covers a wide area, but its limits have not been traced. On the location ground, N.W. 71 and N.W. 2, quartz-porphyries and lavas, with red chalcedony amygdales, are very conspicuous in the Dwyka, and there are also some quartzites, with chert pebbles.

On Vervanhier (Barkly West) there are two wells sunk on black shales with thin, hard ferruginous layers, probably Upper Dwyka shales.

On the main road to Barkly West from Delport's Hope there are good exposures of the lowest part of the till-like Dwyka still adhering to scored surfaces of the Pniel volcanic group. The best examples are on the eastern side of H.V. 47, where the general trend of the striae on the volcanic rocks is W. 36° S.

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South of the bridge across the Vaal River at Barkly there are roadside quarries in thin bedded, greenish shales, associated with Dwyka till; some of these shales contain striated boulders of volcanic rocks and granite.

A well exposed striated floor is to be seen in a ravine leading to the Vaal River not far from The Bend; the striae run W. 46° S. and W. 60° S. The till rests upon the floor at several spots along the course of the ravine.

Intrusive Rocks.

There are many bodies of intrusive igneous rocks in the Hay Division; they may be conveniently divided into three groups: (1) Diabase rocks, which have a similar appearance to the coarser lavas of the Ongeluk series; (2) more basic rocks of several types; (3) Dolerite of the Karroo type.

It is to be remarked that no intrusions of acid rocks, such as granite or quartz porphyry, occur in this area.

The following account is rather slight, because the thin sections of many of the rocks have not yet arrived.

1. *Diabasic Rocks.*

These form three large masses near Niekerk's Hope; two of them are dyke-like in form, and trend nearly north and south on O. 355 and O. 368; the third is an irregularly shaped mass, on which the village of Niekerk's Hope stands.

A thin section from the Niekerk's Hope diabase (1441) shows that the felspar is very much decomposed; it formed intergrowths with quartz in the ground mass, but its original characters are no longer preserved. The augite is much less altered; it occurs in ill-developed prisms, with basal striations, it is frequently twinned on the ortho-pinacoid, and it has a tendency towards ophitic structure, which, however, is not nearly so well developed as in the thick intrusions of the Karroo; it has in places changed to pale green fibrous hornblende (uralite). There is a fair amount of leucoxene in the rock, and other alteration products are epidote and zoisite. These three masses are intruded into the Griqua Town beds.

On Balloch there is a rather broad intrusion, also in the Griqua Town beds. In thin section (1445) this rock is of much the same type as the Niekerk's Hope diabase, but there is less quartz, and the ophitic arrangement of the augites round the decomposed felspars is more marked.

The contact of this diabase with the Griqua Town beds is exposed in a cutting made for the purpose of opening up a galena lode, and the effect of the igneous upon the sedimentary rock is great. The sedimentary rock was a ferruginous cherty or quartzitic material; but whether at the time of the intrusion

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the alterations had taken place which changed the bulk of the Griqua Town beds in this neighbourhood into jaspers and heavy rocks containing crocidolite is not known. The rock within a few inches of the diabase (1446) is now made of a base of quartz, with innumerable flakes or fibres of actinolitic hornblende set in it, and an occasional fibrous plate of crocidolite. The presence of actinolite can be safely attributed to the igneous intrusion, for the mineral has not been observed in the jaspers, etc., of the Griqua Town series, but the production of crocidolite must be assigned to the causes to which it is due elsewhere in the district. These causes are not yet discovered, but they cannot be igneous intrusions. In parts of slide (1446) the actinolite is seen to be added to the crocidolite, in such a way that their long axes lie in the same direction; in ordinary light the whole plate seems to be one individual stained greenish-blue in the middle, but between crossed Nicols the boundary between the two minerals is found to be sharp, and is made obvious by the higher extinction angle of the crocidolite.

On the farm Oudfontein there is a dyke of diabase cutting through the Griqua Town beds in a north-westerly direction, and on the farm Juanana a similar rock traverses the Ongeluk volcanic beds for a short distance. I took both these outcrops for Karroo dolerite in the field, but an examination of the Oudfontein dyke in section (1451) showed that it probably belongs to the pre-Karroo intrusions. It is of the same general type as the Niekerk's Hope and Balloch rocks, but here the augite has suffered much more change than the felspar. There is no ophitic arrangement, both the felspar (an acid labradorite) and the augite occur in ill-developed long crystals, with the interstices filled with felspar and a very little quartz.

It has already been mentioned that some of the diabase-like rocks associated with the Ongeluk series, *e.g.*, the diabase through which the diamond-bearing breccia of Peiser's mine passes, may be intrusive, and other masses which may be of the same nature occur on Taaibosch Fontein, round the south and east sides of the Vlak Fontein syncline, and in the middle of the Ongeluk-Witwater basin at Wit Puts.

2. *More Basic Intrusions.*

In the Griqua Town beds on Piljaar's Poort there is a green fragile rock exposed in a well. The rock is evidently of igneous origin, but the dyke, which lies parallel to the strike of the Griqua Town beds, is only about twenty feet wide. In thin section (1462) the rock is seen to be very much decomposed; there are numerous more or less rectangular long sections of colourless augite, patches of which still remain, largely converted into fibrous hornblende; other crystals, now replaced by a very pale green and almost isotropic substance, may have been a

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rhombic pyroxene. No olivine pseudomorphs are visible. There is a small amount of quartz in the ground mass, but the felspar has been altered beyond recognition.

In many parts of the district wells have been sunk in very much decomposed rocks containing serpentine, but the nature of the rocks is obscure. They are only got from the wells, and they are dug out as an earthy, serpentinous mass, looking rather like "blue-ground" in a decomposed state, without the inclusions characteristic of diamond-bearing ground. Such rocks were seen on Blaauwbosch Poort, Rooi Laagte, Ganna Aar, Kameel Dam, and Kruis Pad in the Griqua Town beds; at Klip Bak, Juanana and Vlak Fontein in the Ongeluk beds, and at the Poplars O. 427 and O. 40 in the Campbell Rand limestones.

One of the least decomposed of these dykes is than on Juanana; it is exposed in a prospecting hole, where copper carbonate, limonite, and specular iron occur in a thin vein in the dyke. Its specific gravity is 3.06. In thin section (1449) this rock is seen to consist of imperfectly developed crystals of augite and pseudomorphs of another mineral, inbedded in a ground mass of fibrous minerals, of which a strongly pleochroic (blue-green parallel to the basal cleavage and orange red at right angles to it) chloritic substance is the most conspicuous. The pseudomorphs have the shape of olivine crystals, but the substance of the pseudomorph is not like that of the usual replacements of olivine, being an aggregate of highly polarizing flakes. Some brown hornblende is present, as an original constituent, and there are iron ores and grains of a strongly refracting substance not determined.

The long dyke on the Poplars and O. 40 is made of bastile pseudomorphs after enstatite imbedded in alteration products and grains of iron ores.

Along the contact with this dyke the Campbell Rand limestone is converted into a greenish hornstone-like mass, with cracks filled with chrysotile running through it.

3. *Dolerites of the Karroo Type.*

The only intrusion known to me in Hay that may belong to this group of rocks is a long dyke, traceable for over eleven miles, from near Postmasburg to beyond Klip Fontein. In the field this rock is extremely like the Karroo dykes, but it has not been examined in thin section, and after the mistake as to the nature of the Oudfontein and Juanana dykes, there is some doubt about the Postmasburg dyke.

Diamond-bearing Breccia.

The only place in the Hay Division where rocks of this kind are known to occur is the Peiser Mine on M. 57.

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The breccia fills a fissure which is of unequal width and of unknown length. So far as the mining operations had proved the position of the breccia at the time of my visit, the fissure is over 300 yards long, and about 60 wide at the widest part. At one place where the fissure is about 40 yards wide, it has a steep dip towards west-north-west. The general trend of the fissure is about N. 40° E.

Where the breccia has been removed from the walls of the enclosing rock, the latter are seen to be covered with slickensides with more or less vertical striations, pointing to the slipping down of the breccia, owing probably to consolidation of the loosely compacted mass.

The general matrix of the breccia is a greenish serpentinous substance, very soft and crumbly, and it contains large and small masses of diabase similar to that of the walls of the fissure, large and small pieces of yellow and black magnetic rocks evidently derived from the underlying Griqua Town beds, bluish crystalline limestone or dolomite from the Campbell Rand beds, small pieces of brown mica, red and brown garnet, ilmenite, and crystals and fragments of diamond.

At the time of my visit the harder, less decomposed, rock which may be expected to underlie the greenish breccia had not been reached; the core from a borehole taken from 132 feet from the surface was almost as soft as the rock obtained from the open workings at about 60 feet from the surface.[1]

Ilmenite is a comparatively scarce constituent of the breccia, and an examination of a fair amount of the material got from the sorting tables did not yield any diopside or others of the minerals that are frequently associated with the diamond-bearing and allied rocks from other parts of South Africa.

A thin section from a core (1163) from Peiser mine shows that the rock is mainly composed of alteration products, serpentine, calcite and chlorite, pseudomorphs after olivine, brown mica and grains of magnitite. Some few isotropic, highly refracting, brown octahedra of very small size may be perofskite, but this mineral is much less abundant than in the Kimberley blue-ground.

Recent Superficial Deposits.

These include gravel, sand, alluvium, and tufaceous limestone.

1. *Gravels.*

Between the Matsap ridge and the Langeberg there are gravels covering gentle slopes at various heights above the present valley bottoms, from 200 feet downwards. A gravel de-

[1] For an opportunity of examining this core and for much information I am indebted to Mr. A. Morkel, the Manager of the Peiser Mine.

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posit about 200 feet above the valley bottom was seen on the farm O. 229 south of Floradale, and the measurement was made with an anaeroid from the loop to the south-east on Valsch Pan; the figure, of course, only represents an approximate estimate.

The pebbles in these gravels are well rounded, evidently waterworn. These gravels extend over a considerable area on the east side of the Langeberg, though their boundaries have not yet been mapped out.

Near Piljaars Poort there are distinct flat-cut rock terraces, with little gravel on them, at a level of 200 feet above the Matsap Loop, where it cuts through the Langebergen.

Gravels occur at many places in river beds which have not contained running water since the area was inhabited by white men.

The broad flat valley bottoms called "loops" are usually occupied by tufaceous limestones or sand, but from wells sunk through these deposits, water-worn stones are usually thrown out. I saw coarse gravel from several wells in the Matsap Loop, from Lucas Dam in the north down as far as its passage through the Langeberg near Bingap. The depth at which the gravel is reached varies from a few feet to fifteen or twenty, but as water is got before bedrock is reached, the total depth of the superficial deposits is not ascertained.

There can be no doubt that at a time not far removed from the present, but before the Griquas came into the country, there was much running water east of the Langeberg. The river courses since then have been filled up with sand and tufa, and are gradually becoming less and less distinct. It is often impossible to recognise the river beds indicated on the Divisional map when one is actually traversing the ground, but they are more distinctly seen from the top of a hill owing to the thicker belt of bushes or low trees along their courses.

Although no water flows at the surface along these river channels, they provide courses for the underground drainage.

The rain water finds an easy passage underground through the sand or sandy soil which covers a very wide area west of the Asbestos Mountains, and when it reaches the bedrock, the greater part of it flows down towards the old main channels, and then along these towards the Orange River. The rate of flow must be slow, because the water has to make its way amongst the sandy and calcareous gravel in the old bed. The wells in these "loops" have the best reputation for withstanding droughts of any in the district; many of them have never been known to give a seriously decreased yield during a drought, though wells in the small kloofs under the Langeberg and elsewhere at a distance from the large loops dry up altogether, or yield very little water under the same conditions. Down the loop the water is usually met with at greater and greater depths.

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This is especially noticeable in the Matsap Loop below the poort at Matsap. The hard impervious Matsap beds evidently make an underground dam, so that the water immediately above it lies near the surface, while below the wells are deep. Near Bingap they are not only deep, but yield, during a drought at least, almost undrinkable water.

2. *Tufaceous Deposits or Surface Limestones.*

Calcareous tufa is found in many parts of the district. The known occurrences may be divided into two classes:—(*a*) those lying above calcareous rocks in such a way that they are probably derived from the latter and deposited on the surface in the same neighbourhood on the evaporation of water drawn to the surface of the ground by capillary attraction or other means; and (*b*) those deposits which occur in the loops and pans, and were not derived from the underlying rock.

The tufas of class (a) are met with almost everywhere on the limestone areas, such as the Kaap Plateau and the country between Groen Water and the Paling ridge. They are also found overlying the Dwyka series along the Orange River, and on the Ongeluk volcanic rocks, though in neither of the latter cases are they so abundant as in the former. These tufas are greyish or yellowish white in colour, earthy or compact, and they enclose grains of sand and clayey material. The upper surface is sometimes very hard and compact, below a varying thickness of from half an inch to three inches of this compact rock the material is usually much softer. The tufas of this kind are found anywhere, on flat ground, gently sloping ground, or even on precipitous places like the scarped edge of the Kaap Plateau, where great masses of dull earthy carbonate of lime have been deposited by water trickling down the surface from the soil on the edge of the plateau, and by water oozing out of the rocks themselves.

The tufas of class (*b*) are restricted to the valley bottoms and the variously shaped pans. They are usually earthy rocks, sometimes hard enough to be used for building, and in many cases the outer surface of portions partly separated from the bulk of the rock by wind or rain erosion are very hard.

They contain water snails and bivalves, though the latter are only got from low down in the tufa when wells are being made. At Lucas Dam Mr. Turner told me he found many of these bivalves at about 25 feet from the surface, but there were no specimens left at the time of my visit, and the well had water in it. The shells, from Mr. Turner's description, were evidently *Anodon* or *Unio*. From the tufa in the Matsap Loop below Matsap I obtained several specimens of a shell very like *Physa tropica*, Krauss, which is a living species in many parts of South Africa.

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From the tufa at the Griqua Town water cutting there were got some elephant and rhinoceros bones, but no representative collection of the bones thrown out from such excavations has been kept.

3. *Sands.*

In all the valleys west of the Asbestos Mountains there is more or less sand of a reddish or yellowish colour, and as one approaches the Langebergen, the sand increases in amount.

From wells between the Langeberg and the hills near Matsap, especially east of Baken's Kop, on Langeberg, the sand is known to be 20 feet deep in spots on the flat ground.

In the wide sandy valleys which lie east of the Langebergen north of Piljaar's Poort, there are well-marked ridges of sand traversing the valley from side to side; they rise from 10 to 50 feet above the flat ground between them, and their trend is nearly east and west. There was a fairly thick covering of bush and grass on all the sandy country during my visit, although owing to the long drought, I was informed, the veld was in a very poor condition.

At the present time the sand on the east side of the Langebergen, and also in the country immediately west of the range, cannot be moved about by the wind to any considerable extent, on account of the protection afforded by the vegetation. Supplies of red dust are undoubtedly received from the eastward, brought in by the strong east winds. The various strata exposed in the hills of Hay must yield dust and sand which is not carried down to the Orange River at the present time. The western part of the district is certainly being levelled up by the preponderance of deposition in the valleys over the amount of material carried away by wind and water.

4. *Pans.*

Pans are not abundant in the Hay district. On the Kaap Plateau and on the Asbestos Mountains the only pans seen were of quite small dimensions, 20 or 30 yards wide. They have floors of calcareous mud or tufa in the limestone areas, and brown mud floors on the Griqua Town beds.

The large pan at Matsap lies just behind the poort of the Matsap Loop, not in the direct course of the loop, but some 500 yards south (left) of it. It is separated from the low ground near the poort by a slight rise of whitish calcareous soil.

At the time of my visit the pan was dry, but water is found at a depth of eight feet. This water contains much salt, and is put into shallow iron pans when the salt separates out. The last part of the liquid is not allowed to evaporate, for it contains some nitrate, which is held to be injurious for stock. A considerable quantity of salt is thus obtained annually for use in the district.

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A sample of salt deposited in the pan itself was not obtainable, so I took for analysis a quantity of sandy salt from a heap thrown out from the iron pans, into which much sand had been blown, an accident that often happens under the present conditions of evaporation. This rejected salt must be more like the natural deposit in composition than the salt as prepared for sale.

An analysis of the soluble part of the material was made by Mr. J. G. Rose, of the Analytical Laboratory:—

NaCl (common salt)	73.80
$MgSO_4$ (Epsom salt)	16.98
$MgCl_2$	4.63
$CaSO_4$	2.16
KNO_3 (nitre)...	2.11

Fresh water, or rather very slightly brak water, is got from a well about 200 yards from the pan and nearer the old river bed, and good water for stock comes from a small spring on the north-east side of the pan.

5. *Nitre in Hay.*

This substance occurs in between the projecting layers of jasper on the krantzes in the Griqua Town beds. It is crystallised in such a way that the mass has a fibrous appearance, and the fibres are perpendicular to the enclosing layers of rock. The nitre is white or slightly stained, and the layers are of various thicknesses; those I saw did not exceed two inches in thickness, and they thin away inwards, for the spaces they occupy are due to weathering from the surface.

A few farmers make a little money each year by collecting the nitre, which is picked out with a knife or chisel; but, so far as I could ascertain, there is no body of nitre large enough to be worked on a commercial scale. Unsuccessful attempts have been made to wash the ground under the krantzes, and thus obtain the nitre disseminated through it.

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GEOLOGICAL SURVEY

OF

PORTIONS OF THE DIVISIONS OF VRYBURG AND MAFEKING.

BY

ALEX. L. DU TOIT.

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GEOLOGICAL SURVEY

OF

PORTIONS OF THE DIVISIONS OF VRYBURG AND MAFEKING.

By ALEX. L. Du TOIT.

I. Introductory.

The area surveyed consists of a strip of country averaging nearly forty miles in breadth, and extending along the Transvaal border from Dry Hart's Siding in the south to Ramathlabama Spruit in the north.

The Divisional maps of this part of the Cape Colony, which are the only ones available, are on the rather small scale of 2,000 Cape roods (4·7 English miles) to an inch; it was therefore impossible to draw in the geological boundaries with much detail.

1. *Natural Features.*—The country is flattish or slightly undulating, with low hills and ridges, and occasionally a few abrupt kopjes of no great altitude.

Around Vryburg and to the north the surface is remarkably flat, and rises gradually towards the Mafeking border, along which is situated the main watershed of this part of Bechuanaland. The height above sea-level of the watershed is greatest on the Transvaal border (4,600 feet), and this falls somewhat towards the west.

The southern portion of this area is drained by the Dry Harts River, a tributary of the Vaal. The river channel immediately to the south of Vryburg is deep and narrow, but at Brussels Siding it opens out into a broad and fertile valley.

North of the watershed are branches of the Molopo River, *e.g.*, the Mosita, Setlagoli, and Maretsani Rivers and the Ramathlabama Spruit, which carry off the rainfall into the Kalahari.

This portion of Bechuanaland is a gently rolling country, with a gradual fall towards the north-west; hills and kopjes are rare, and are formed invariably by hard rocks, such as quartz-porphyry, quartzite, or magnetic rocks.

At one time the country supported an extensive arboreal vegetation, but owing to the demand for timber at the diamond mines, and to the continual grass fires, almost the entire area within easy reach of the railway has been deforested.

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Some twenty miles or thereabouts from the railway the forest country is first found, and away to the north and north-west there is a monotonous stretch of well-wooded ground. The vegetation is chiefly composed of various acacias, such as the Kameel boom (*A. giraffae*); the Hakdoorn (*A. detinens*) is fortunately not abundant. Around Vryburg and towards the south the country is dotted with Vaalbosch (*Tarchonanthus camphoratus*). Various grasses are usually abundant.

Water is only met with in pans and rivers after falls of rain; for the soil is so light and sandy that the moisture is readily absorbed. The farmers have in consequence to obtain all their water from wells, boreholes, or dams. The best supply is obtained from the dolomite; the diabase often yields water in considerable quantity, but the granite is a rather uncertain source of supply.

2. *The Geological Formations.*—The only accounts of the geology of this interesting district are a paper by Mr. G. G. Holmes* on the area west of Vryburg, and brief references to the formations at Mafeking by Passarge, Hatch, Philippi, and others.

The rocks which build up this portion of the Cape Colony are all, with the exception of the Dwyka formation, older than the Cape system. Some of the formations are new, and have therefore been given local names; others have already been described from the Cape Colony or from the Transvaal.

In descending order, the rocks may be arranged as follows:—

Recent.	Superficial deposits:—alluvium, river-gravels, sand, and calcareous tufa.
Karroo System.	Dwyka series:—shales, and boulder-clay.
Transvaal System.	Campbell Rand series:—dolomites, limestones, and cherts. Black Reef series:—quartzites, with interbedded volcanic rocks.
Ventersdorp Series.	Diabase formation:—diabases, amygdaloids, breccias, and conglomerates. Botman's Poort sandstones and conglomerates. Zoetlief Beds:—quartzites, flagstones, and cherts; quartz-porphyry, and trachyte; quartzites, flagstones, and arkose.
	Kraaipan formation:—magnetic quartzites and slates; phyllites; sericite, chlorite, and calcareous schists.
	Granite and gneiss.
	Schists and other rocks included in the granite and gneiss.

* Trans. Geol. Soc. S.A., Vol. vii., p. 130, 1905.

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There are also a few intrusions, chiefly basic in character; some of these belong to the Karroo dolerites, while others are of much greater age.

II. Schists in the Granite.

At a number of localities the granite contains inclusions of material that must have been derived from older formations. These inclusions are of irregular shape, and range in size from fragments having an area of a few square inches to patches covering an acre or more in extent.

Some of these, *e.g.*, the sillimanite and cordierite rocks, probably represent highly metamorphosed sedimentary material, but the origin of the hornblende and associated schists is by no means clear.

1. *Sillimanite Rock.*—This occurs on the farm Oaklands, a little to the north of Mafeking, the outcrop being a single mass in the midst of red sand. About a quarter of a mile away, at the homestead, the granite is exposed in wells.

In the hand specimen the rock is light in colour, very much like clouded felspar, and with purplish mottlings, due to minute crystal aggregates of sphene. The material is massive, without any schistose structure, and its ability to withstand the blows of a hammer is nothing short of marvellous.

In thin section (1428) the great bulk of the rock is seen to be composed of bundles and aggregates of sillimanite needles (fibrolite); sometimes these are arranged close together in parallel positions, so as to resemble large crystals. Among these fibres occur larger and more well-defined prisms of the same mineral, which are usually elongated and indefinitely terminated. A few areas of clouded material showing crystallographic outlines may perhaps represent andalusite. Sphene, deep yellow-brown in colour, is present in great abundance, sometimes in well formed crystals. The specific gravity of the rock is 3.246.

2. *Cordierite Gneiss.*—On the farm Regen Vlakte, north of the Saltpan, a well has been sunk close to the homestead, through rather decomposed muscovite-granite (accompanied by aplite and pegmatite) into a hard greenish quartzitic-looking rock.

In the hand specimens these rocks are seen to owe their dark green colour to the abundance of dull green pseudomorphs (pinite) after cordierite. Muscovite has been developed enclosing the other minerals ophitically, and sometimes attains such a size that over an area of several square inches light can be reflected from different parts of the same crystal.

In thin sections (1406, 1407) the cordierite is seen to have some approach to crystallographic outlines, and is in large individuals enclosing quartz, leucoxene, and little zircons.

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The mineral has been entirely altered to a pale greenish aggregate, with very low polarisation colours, but the pleochroic halos still exist around a few of the inclusions. Quartz forms large patches; muscovite is abundant, and includes all the other minerals. Felspar is present in variable quantity, always clouded, and brown and opaque at the edges. Leucoxene is abundant, and there are a few small pink garnets, and numerous little zircons.

Some of the rock is light in colour (due to abundant felspar), with large green pinite pseudomorphs as much as one-third of an inch across; muscovite is then practically absent.

There are bands of dark hornstone in the formation, which are sharply defined from the surrounding rock.

No outcrops are seen in the neighbourhood, as the depth of soil is here considerable.

3. *The Hornblende and Associated Schists.*—These rocks, which vary exceedingly in character, have an extremely great resemblance to many of the sheared basic intrusions so commonly found in granitic areas; the presence, however, of veins of granitic material ramifying through the schists is sufficient to show that the latter are earlier than the granite. Basic rocks seem to be most common, but acid varieties are probably quite as abundant, though their resemblance to the gneiss is so great that they readily escape observation.

(a) Localities.—One of the best localities where these rocks may be studied is about 2¼ miles south of Maribogo Station, in several trenches along the railway. The granite is a foliated muscovite variety, medium-grained and passing into banded muscovite and biotite gneiss. The schists form irregular streaks and patches in the gneiss, and the foliation in the two formations generally has the same strike, a little north of east, and dip, to the south at angles of from 40° to 60°.

None of the inclusions can be traced continuously for more than a few yards, for the rock is penetrated by numerous veins of granite and aplite, both along and across the foliation planes.

In many places the material of the schists is permeated with thin films of granitic rock, and there has been such an intermingling of material that it is difficult to discover the original limits of the inclusion.

Quartz veins traverse the gneiss and schists in various directions, and there are numerous little faults and slips in the rocks with their faces coated by films of mica.

The more acid schists are nearly always decomposed to a sandy material where exposed in the cuttings, but they are seen in the fresh condition in some knobs of granitic rock, and are traversed by veins of that material along and across the foliae.

The laminae of the schists are often greatly contorted, but the foliation planes in the gneiss surrounding the inclusions generally run evenly.

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At Setlagoli, on the right bank of the river, there are several most interesting exposures of these schists, some of which are contorted garnetiferous varieties. The strike of the foliation planes of the schists is sometimes coincident with those of the gneissic granite, but at other times it is almost at right angles to the latter.

Veins of granite, aplite, and quartz ramify through the schists, and in many places follow the contorted foliation planes.

For several miles down the Molopo River, just west of Mafeking, there are exposures of schists and granite, so interleaved as to form well-banded hornblendic gneiss, with foliation planes striking nearly due north. The composite nature of the material is everywhere made apparent by the lenticles of schist, cut by veins of granite and aplite.

At the junction of the Molopo with the Madibi Spruit there are fine outcrops of contorted schists, some of the layers being composed of large prisms of black hornblende.

A large area covered by similar rocks exists on the Ramathlabama Spruit, about two miles above its junction with the Molopo River.

These schists resist weathering to a greater degree than the enclosing granite, and their extensive development is indicated by the number of blocks found embedded in the red sandy soil of the district.

(*b*) *Petrographical Description.*—A thin section (1403) of an acid variety shows a large quantity of biotite in small flakes, mostly altered to chlorite. The ground mass consists of quartz, orthoclase, and plagioclase, the felspars being of rather large size. The structure is gneissose.

Of the basic schists there are many varieties, and quite commonly we can trace a regular change in the nature of the material from the centre of the inclusion to the contacts with the granite.

Thus, generally speaking, the cores are well-banded rather granulitic rocks, mostly garnetiferous, and containing hornblende, augite, and epidote. The rock passes into hornblende-augite-schist, biotite-hornblende-augite schist, and then into a talo-schist, with more or less unaltered ferro-magnesian mineral.

The borders of the inclusions were affected to a greater degree by the shearing movements that caused the foliation of the granite, and they were also acted upon to no small degree by the granitic magma. The interchange of material is sometimes shown by the production of quartz and orthoclase in the rim of the inclusion and by the development of biotite in the surrounding granite.

The following is a description of some of the rocks in thin section:—

No. 1397, from centre of an inclusion near Maribogo:—A well-banded granulitic rock, showing different layers character-

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ised by the predominance of different mineral constituents. Green hornblende sometimes showing approach to idiomorphic outlines and pale greenish augite with similar characters; the two are usually mutually interfering. Plagioclase felspars are abundant; in some parts of the slide they are clear and have rounded outlines, in other parts they form clouded aggregates. There is sphene and garnet, while epidote is present in large quantity, and has been formed after the above mentioned minerals. Zoisite has been produced last of all, and is moulded on the epidote, garnet, etc.

This grades into No. 1398, which is quite different. The hornblende occurs in parallel intergrowth with pale augite. The latter, but not the former, has little tubes of quartz ramifying through it, recalling a micrographic structure. The spaces between the crystals are partly filled by epidote, with similar tubular structures. Felspar is present, but is rather clouded, and contains calcite.

No. 1399 is a typical hornblende schist. The hornblende is abundant in deep green prisms, which usually include quartz in the form of blebs. There is a little clear plagioclase felspar.

This rock passes into a biotite-hornblende-augite schist, and that again into a highly sheared talcose-schist.

The section (1400) shows plates and fibres of talc and serpentine, the latter having probably been formed from biotite (through chlorite). The rock contains calcite, magnetite, and haematite. This talcose-schist occurs close to the junction with the granite.

At Setlagoli the rocks are somewhat similar.

No. 1412, from the core of a large inclusion, shows large pink garnets in irregular grains and aggregates enclosing apatite and sphene. Pale green pyroxene is usually bordered by green hornblende, and may show a diallagic structure. The hornblende commonly contains little tubes of quartz, which expand in places to form blebs; this reverses the conditions seen in No. 1398. Sphene and apatite are also included. Epidote is abundant in large, nearly colourless plates, ramified by veins and tubes of quartz. Quartz is present also in small, irregular areas, and so is calcite. Sphene is present in unusual quantity, in granules which are crowded together to form aggregates; apatite is also very abundant. Felspar was the last mineral to form, and surrounds all the other constituents. It is very much clouded, but still shows repeated twinning.

No. 1411 is a well foliated rock, containing very large prisms of pale yellowish-green augite, with their longer axes arranged in the same direction. Felspar, slightly clouded, fills in spaces between, and sometimes encroaches upon, the augites; it sometimes shows repeated twinnings. Sphene is abundant as inclusions in both these constituents.

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The rock passes into a dark talcose rock, with somewhat schistose structure, and containing a good deal of unaltered augite.

III. The Granite and Gneiss.

Although granitic rocks cover the greater portion of the Mafeking Division, there are but few places where any considerable natural exposures can be seen.

The only places where the rock can be well examined are at Maribogo and down the river to Setlagoli, on the Mosita Native Reserve, at Kraaipan, and along the upper portion of the Maretsani River; elsewhere there are isolated outcrops, and its presence underground is inferred from the character of the soil or from the material brought up during well-sinking operations.

(1) *Petrographical Description.*—The granite is usually a white, grey, or pinkish gneissic variety, containing muscovite, and nearly always medium grained and never porphyritic in character.

In a few places the mica is biotite, and muscovite may or may not be absent.

In most of the granites there seems to be a certain amount of oligoclase felspar, in addition to orthoclase and microcline. In a specimen (1395) from Maribogo, there is well shown the production of lamellar twinning in orthoclase felspars in certain parts of the crystals that have been subjected to strain.

The microcline is the last constituent to crystallise, and surrounds and penetrates between the earlier formed minerals. The microcline resists alteration both chemically and physically to a greater degree than the orthoclase and oligoclase.

Granites, other than micaceous varieties, are also represented.

From Zwart Laagte, near Setlagoli, a sample (1415) taken from a borehole proved to be a hornblende-granite.

At Oaklands, north of Mafeking, a well has penetrated an augite-granite. The thin section (1427) shows a granulitic aggregate of quartz, orthoclase, and oligoclase, in which are set irregular grains of feebly pleochroic greenish augite. Another specimen from this well has a similar mineral composition, but the greater bulk of the rock consists of pyroxene.

At the farm West End, in the lower portion of the Maretsani River, there are banded rocks of nearly similar composition.

The thin sections (1413, 1414) show granulitic gneisses, with pale green pyroxene and epidote; the latter may be an original constituent. In the first section apatite is most abundant; in the second sphene forms numerous crystals, with rather well-developed faces.

(2) *Pegmatites and Veins.*—Pegmatite veins are very abundant, but seldom have a width of more than a few inches. They

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ramify in all directions through the granite, but a little north-east of Kraaipan the majority of the pegmatites trend in a northerly and southerly direction. Graphic intergrowths of quartz and microcline felspar are not very common, but there are good examples at Maretsani Siding. Muscovite predominates over biotite as a constituent. About half a mile south-east of Kraaipan Siding a pegmatite contains a certain amount of fluor-spar and pyrites.

Aplite veins are sometimes common, but usually only occur penetrating the patches of schist which have been included by the granites. They are never more than about a foot in width. Under the microscope the rock proves to have a granulitic structure.

Granite Veins.—I have only noticed one granite vein, about twelve inches in width, at a point on the railway two and a half miles south of Maribogo Station. It cuts nearly vertically through both the granite and the included schists.

Quartz Veins.—These are very abundant, from small threads up to reefs as much as 40 feet broad. They consist of milky-white quartz, sometimes rather chalcedonic, and in places contain small amounts of tourmaline or iron pyrites, but they never appear to carry any appreciable amount of gold. They have no fixed direction of strike.

Pyrophyllite Rock.—An occurrence of this material was noticed along the railway two and a quarter miles south of Maribogo Station. It forms a vein about 4 feet wide cutting nearly vertically through the granite. Some quartz veins in the latter are truncated by this material. The rock is tough, though soft, and is composed of numerous small pearly plates of pyrophyllite. It is stained by iron compounds, and contains perfect little octahedra of magnetite. The material resembles a talc-rock to a great degree, but the absence of magnesia and the presence of alumina were proved chemically.

As to the origin of the material it is impossible to be certain. Pyrophyllite is produced by the alteration of potash felspars, and is one of the intermediate stages during the formation of kaolin. Possibly it may have been formed from an acid intrusive rock or from material in a belt of crush and weathering in the granite.

(3) *Foliation.*—With the exception of those in the Mosita area, all the granites show foliation to a greater or lesser degree, so that in many places the term gneiss is more applicable. Around Maribogo and Setlagoli these foliation planes have a very constant strike a few degrees north of east; on the Maretsani River at the Railway Siding, and again further down at West End the strike is about north and south. The dip of the foliation planes is variable, and in some places they are slightly contorted.

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A certain amount of the foliation appears to have been produced by the flow of the molten material during the period of injection. This is shown in several ways. Firstly, in quite a number of places the minerals in the pegmatite veins are quite unaffected and undistorted. Secondly, and this is well shown at Setlagoli, the foliation planes in the granite do not pass through the included schists. The latter have their own foliation planes, which are contorted, and strike north and south, *i.e.*, almost at right angles to that of the granite.

Lenticular patches of schist very often conform in dip and strike with the direction of foliation of the enclosing granite, in which case the two rocks have parallel foliation planes, but this is apparently largely due to the twisting round in the molten mass of these patches of rock, so that their larger surfaces were set parallel to the direction of flowing.

It is equally true that later movements have produced shear structures in the granite, and at Maretsani Siding the mica plates in the pegmatite veins have been bent, while some of the crystals of felspars have been much distorted. The shearing is most intense in the proximity of the thrust-planes bounding some of the belts of the Kraaipan formation. A specimen from the farm Holland shows the following characters in thin section (1430) under the microscope:—

The felspars are drawn out in the direction of shearing, and are faulted and broken, but usually resist the stresses far better than the quartz; the ground-mass consists of a medley of fragments of quartz and felspar, and the planes of shearing are marked by films of muscovite.

Another example (1405) from the contact with the magnetic rocks at Gemsbok Pan shows granulitised quartz, and sheared and distorted muscovite plates, while the felspars have been replaced by aggregates of quartz and some micaceous mineral.

A coarse-grained granite from Mosita (1417), which is almost devoid of mica, shows lines of fracture and crush which have been lined with chalcedonic and filled in with opaline silica.

IV. The Kraaipan Formation.

There is in the Mafeking Division a considerable development of schists and magnetic quartzites and slates, which are closely paralleled by certain rocks in Bloemhof (Abelskop), Pietersburg, Barberton, Swaziland, and elsewhere.

These schists and ferruginous rocks have been grouped together by different observers under the names of Barberton beds, Swazi Schists, Namaqualand Schists, and "Primary-formation."

As these terms are not very well defined, and in some cases misleading, it has been considered justifiable to give the Bechuanaland rocks a purely local name, especially as there is nothing

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as yet to indicate a similar age for these various scattered occurrences of rocks, except their lithological resemblances.

Distribution.—The formation must at some very early period in geological history have covered a great area in this district; earth-movements and denudation, however, have removed the greater portion, and left but little except three narrow areas, which form rather discontinuous and more or less parallel belts.

The *Eastern belt* is that at Madibi, having a general north and south trend.

The *Central belt* occurs at Kraaipan, and extends southwards into the Khunwana Reserve (Transvaal), while in the opposite direction it stretches across the Maretsani River, and then forms a series of detached ridges, which are very prominent at Pitsani.

The *Western belt* is well developed at Mosita, but has not been followed northward beyond Blik Plaats. Southwards there are ridges at Wonder Klip, and the rocks project through a cover of diabase at the Saltpan and at Monjana Mabedi.

Tectonic Geology.—Deposited originally unconformably upon the granite, the beds have been intensely folded and sheared, so that in but few places are these two formations found preserving their original relations.

Faulting and thrusting have taken place on an extensive scale, and in a great number of outcrops the boundaries on one or both sides consist of thrust-planes.

The formation being of considerable thickness, it is evident that the lithological differences noticed between different outcrops may be due, partly to the fact that beds caught between the thrusts have been derived from different geological horizons, and partly to the nature and degree of the metamorphism which these beds have undergone.

There appear as well to be certain lithological differences, which can only be explained by an alteration in the character and nature of the original sediments along or across their strike.

General Lithological Characters.—For general purposes the rocks of the Kraaipan formation may be arranged in four classes:—

(*a*) *Ferruginous rocks.* magnetite-quartz rocks (quartzites and slates), magnetite-actinolite rocks, and ochreous quartzites and slates.

(*b*) *Cherty rocks*: massive and banded cherts, ferruginous cherts, and jaspilites.

(*c*) *Schistose and slaty rocks*: sericite, actinolite, and pyrophyllite schists.

(*d*) *Calcareous rocks*: limestone, ferruginous dolomite, and calcareous schists—these are poorly developed in this area.

The rocks are all highly veined with quartz both along and across the bedding planes, and, as will be seen later, these reefs have apparently been produced at different geological periods.

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Stratigraphical Divisions.—The formation may be divided up into three portions:—

(i) a lower group, characterised by a very massive bed of magnetic quartzite and alternations of thinner beds of that rock and phyllite, etc.;

(ii) a middle group, composed essentially of cherty rocks, with but an occasional slaty or quartzitic bed; and

(iii) an upper group, in which magnetic slates, cherty rocks, phyllites, and schists alternate rapidly in beds of no considerable thickness.

Of the limestones, some belong to the lowest division, but the exact horizons of the others are not known.

The formation, or rather that portion of it represented in the Mafeking Division, must be at least 10,000 feet in thickness, even after making due allowances for the repetition of some of the beds by folding.

Owing to the recent discovery of gold at several places, notably at Madibi, the Kraaipan formation acquires considerable interest, hence the following detailed description of the various belts of rock.

Description of Occurrences.

I. *The Central Belt:—Kraaipan-Pitsani.*

It will be most convenient to commence with the description of the outcrops at Kraaipan, for there the formation is least disturbed, and attains its maximum thickness, while the unconformable relation of its base to the granite is well shown (see fig. 1); (the two cross-sections are taken along lines four miles apart).

At Kraaipan Siding the belt is not much more than half a mile across, but when followed northwards this increases rapidly, and on Wodehouse Kraal it attains a width of three miles. The lowest bed of magnetic quartzites forms a long line of rugged black kopjes, broken at two points where its outcrop has been shifted westwards by transverse faults for a considerable distance. The chert zone forms a low, well-wooded, and more regular ridge, while the strata forming the upper zone are more or less concealed by sand.

The actual base of the formation is exposed along the railway west of Kraaipan; elsewhere the junction with the granite is hidden by sand. The massive muscovite-granite contains at this point several bands rich in biotite, which cross it, and which are now sheared into a biotite-gneiss.

Upon the granite and gneiss rests a silvery mica-schist, with foliation planes dipping eastwards at an angle of about 70 degrees. This passes into greenish sericitic schist and soft phyllite, which is followed by the lowest magnetic quartzite, with a dip of from 45 to 50 degrees. The thickness of these

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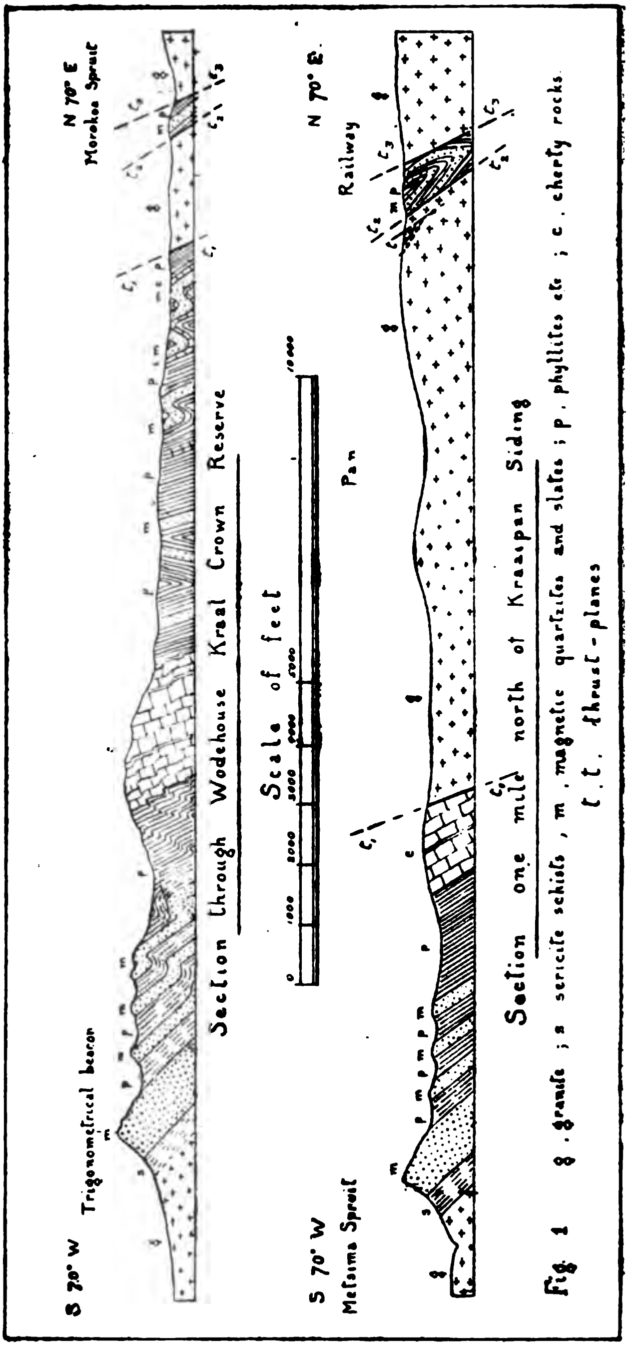

Fig. 1 g. granite ; s. sericite schists, m. magnetic quartzites and slates ; p. phyllites etc ; c. cherty rocks.
t. t. thrust-planes

basement schists cannot be more than about 50 feet, and in all probability the planes of foliation cross those of bedding. This magnetic quartzite, about 60 feet or more in thickness, is followed in turn by alternations of magnetic slates and greenish phyllites and sericite schists, the softer beds being but seldom exposed. Some prospecting shafts have proved this formation, and a well along the railway just west of the siding is sunk in a hard chlorite slate, and gives a good supply of water.

North of Kraaipan Siding, the chert zone first appears, and is well exposed on Wodehouse Kraal, where prospecting shafts have been sunk in it. These cherty rocks vary in colour from white to blue-black, and are usually well banded, and pass on the one hand into cherty rocks with magnetite and on the other into massive brown cherts with banding but feebly developed. Thin layers of greenish and ferruginous phyllite are also present.

At a point about a mile north-north-east of Kraaipan Siding there are thin beds of actinolite-magnetite rocks, like those to be described later from Maribogo.

The eastern contact with the granite is nowhere seen, but the position of a dislocation can be fixed fairly closely by means of scattered outcrops. Towards the north the thrust-plane gradually cuts out the higher beds, and on Lenton the whole of the formation has been overlapped by the granite.

At the boundary between Lenton and Spanover there are thin inconstant red bands in among the black quartzites, the red colour being due to haematite.

East of the main outcrop there are evidently two nearly parallel thrust-planes, by which portions of this formation have become wedged in the granite.

The patch two and a quarter miles north-east of Kraaipan is of interest, since a small opening along the railway show a fault separating magnetic slates from a foliated granite. A number of prospecting trenches exist here, and show the character of the beds very clearly, besides revealing their rapid change both of dip and strike.

North of Wodehouse Kraal the distance between the thrust-planes increases to about a mile, the rocks between them including the chert zone and a certain thickness of the beds above and below it. This belt crosses the Maretsani River, and along the banks there are good exposures even of the bands of soft green phyllite. A small patch of breccia containing blocks of crushed granite, magnetite rock, etc., marks the position of the eastern thrust.

On the north bank the formation forms Methuen's Kop, the feature being due to the hard banded cherts, which here contain thin layers of red jasper. The chert becomes more ferruginous above and below.

The belt of rock terminates abruptly at Methuen's Kop; to the north are wide sandy flats, supporting a very scanty vege-

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tation, and no rock is exposed. The termination may possibly be due to the rapid approach and intersection of the two thrust-planes.

Midway across these flats, between the Maretsani and the Molopo Rivers, there rise out of the red sand two prominent hills, known as the Mosadiapitsi Kopjes.

On the eastern hill are massive magnetic quartzites, with a strike a little north of east, which pass abruptly into a hard brown banded limonitic rock, cherty in places. This brown rock probably overlies the other, but whatever the order of succession, there is a considerable amount of inversion of the strata as these are followed along the ridge.

The western hill, on which the beacon stands, consists of extremely folded magnetic quartzites, the strike and pitch of the folds altering rapidly even within very short distances. The axis of each fold is marked by very great contortion, these minor wrinklings being of an isoclinal character.

Immediately west of Pitsani is another great ridge, which is continued north of the Molopo into the Bechuanaland Protectorate.

The river runs in a narrow gorge about half a mile in length, and in places about 200 feet deep, so that a splendid natural section through the formation is thus afforded. The rocks are remarkably massive in character. The magnetic quartzites form thick layers, which are broken up into great cubes by means of joints; the slates are ochreous, and in but thin bands. The dips are at angles of from 45° to 75° towards the south-east, and the strata are traversed by quartz veins, often of no small width. Further down the river are flats, with sand and pebbles, and then sheared mottled ferruginous and micaceous quartzites and green sericite schists. To the south is a flat of red sand, with small outcrops of rock here and there.

Along the Molopo River, between Pitsani and Mafeking, are several strips of this formation, forming a link between the rocks of the central and those of the eastern belt.

About three miles east of Pitsani, but on the northern bank of the Molopo, is a narrow belt of creamy crystalline limestone with an easterly strike. The rock is cherty and ochreous in places, and shows signs of shearing; it contains a certain amount of magnesium carbonate. Since it passes into ferruginous slates it must be considered to belong to the Kraaipan formation.

On the Piring Spruit, about a quarter of a mile above its junction with the Molopo, is a narrow belt of ferruginous and cherty quartzites, not more than a hundred yards wide, and striking a little south of east. It contains numerous layers of white quartzite a few inches in thickness, and is bounded on either side by a basic igneous rock.

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Close to Jan Massibi's stad, and again a few miles west of Sanie's stad, the Molopo is crossed by narrow belts of magnetic-quartzite, having a north-easterly trend.

As the granite (with included schists) is in each case seen within a few yards of the ferruginous rock, it is very probable that these are infolds of the lowest magnetic quartzite, with the basal sericite schists not developed.

II. *The Eastern Belt:—Madibi.*

On account of the auriferous character of some of the rocks at Madibi, this is the most important outcrop of the formation.

The strata are very badly exposed, and in several places there are wide stretches of either sand, black earth, or river-gravels; our knowledge of the rocks forming this belt would therefore be very small were it not for the numerous trenches and other artificial openings.

On the farm Weltevreden, along the Maretsani River, is a small opening, showing a coarsely crystalline magnetic quartzite in contact with gneissic granite. The junction with the granite is very sharp, and the rock shows no signs of contact metamorphism. The bed forms a little syncline, pitching south at a very high angle.

On the south side of the Maretsani River, in the angle between it and the Transvaal border, are openings in an inlier of granite and the Kraaipan beds, surrounded by diabase. The trenches show sharp junctions between the coarse magnetic quartzites and the granite, and the beds are probably infolded in the latter, for neither the granite itself nor the pegmatites which traverse it send tongues or veins into these quartzites and slates.

It is on the boundary between Kirby and Stoneham that the Madibi belt proper commences; south of this there is nothing but the later diabase. At the beacon K. 4 there are several openings, two of which expose the junction with the granite. In one of these the contact is apparently a fault-face, but in the other the strata are bent into an arch over the granite, and the axis of the fold dips away at a moderate angle to the north.

There is a layer of sericite-schist a few feet in thickness between the granite and a rather unusual type of iron-ore rock.

The latter consists of crystalline quartz slightly bluish in colour, and much resembling vein quartz, but with the bedding planes marked out by rows of haematite crystals.

Apparently the original sediment was less ferruginous here and more siliceous than usual, for the rock passes upward into a magnetic-quartzite.

On Eastwood openings show the dips to be rather variable, often either to the north or south. These dips, taken into conjunction with the evidence from the exposures on Kirby and

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Weltevreden, show that in this part of the district the folds which form the belt, and which trend north and south, are crossed by transverse flexures, giving rise to detached basins in the granite.

However, from Eastwood onwards the belt is continuous, and the gneissic granite is exposed on one side or the other in wells. Apparently the folds must pitch in a northerly direction, and from Holland onwards the boundary on each side is most probably a thrust-plane. On the latter farm a finely sheared granite appears in an opening on the west side of the ridge, while a little distance further north there is a shaft in a highly sheared ferruginous dolomite associated with magnetic slates.

On the east side of the ridge, at the northern homestead, there is an excavation in sheared granitic gneiss, while 60 yards to the west is a deep shaft in green mica schist and schistose green micaceous quartzite.

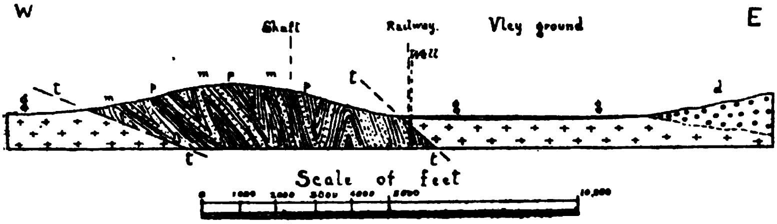

FIG. 2.—Section through Madibi. *g*, granite; *m*, magnetic quartzites and slates; *p*, phyllites, etc.; *d*, diabase and amygdaloid; *t*, *t*, thrust-planes.

Along the east side of the ridge from Holland to beyond Madibi there are several openings, showing gneisses ranging from muscovite to biotite varieties. In the well along the railway at a point a quarter of a mile south of the siding, the gneiss is apparently underlain by a talcose-phyllite. Probably this well has been sunk through the eastern thrust-plane (fig. 2).

The numerous trenches which have been excavated all along this ridge, usually in a direction across the strike, show the nature of the formation and the structure of the belt. As indicated in the accompanying section (fig. 2), the beds are arranged with some approach to a fan-structure. In many of the trenches either the crest or trough of a sharp fold is visible, with the two limbs pressed closely together. The folding seems to be fairly regular, and to have considerable amplitude.

The rocks are usually thinly-bedded, and there are hardly any bands of magnetic quartzite more than a few feet across. The formation consists of layers of evenly bedded magnetic and haematitic quartzites and slates, with greater thicknesses of phyllites, and sericite, chlorite, and calcareous schists.

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Usually there are rapid alternations of harder and softer rocks, and it is very difficult to follow the same bed for any distance with certainty along the strike, even where the cuttings are quite close together.

There are several prospecting shafts close to the railway, but the description of the auriferous material exposed by them will be given later.

North of Madibi the formation can be followed for several miles, for the rocks are occasionally shown in trenches or shafts. The belt then passes below vley ground (black earth and pebbles), but there are openings again at a point about a mile and a half south of the beacon K 14.

On the ridge on which K 14 stands, the formation is not exposed, owing to a thick capping of ancient river-gravels, but the beds probably continue below ground, and are exposed in the valley of the Molopo River, in a trench a little below the spot known as Willow Dam, beside the road to Pitsani.

Here there is a great development of green phyllite and micaceous and quartzitic schists, with only a very small amount of ferruginous rock. The belt is traversed by numerous quartz veins, but none of these have proved to be auriferous.

The width of the outcrop is narrow; the strike is a little north of west and the dip easterly.

On the west side of the belt there is a zone of highly crushed and silicified gneissic rock, about 250 yards in width. The rock has been so shattered and crushed that in places only fragments of the felspar can still be recognised; there is, however, a gradual transition westwards into a muscovite-gneiss. In much of the altered material lenticles of rock occur which have escaped crushing to a greater or less degree, and in which the gneissic structure is yet visible.

The crushed material appears to have been firmly cemented with secondary silica, and its mode of occurrence suggests that it marks the position of the western thrust-plane.

Between the Molopo and the Ramathlabama Spruit little knobs of magnetic quartzites appear now and then, through the thick mantle of red sand.

III. *The Western Belt:—Monjana Mabedi—Mosita.*

In the Vryburg Division this formation has been overlapped by the Diabase, and the outcrops at Monjana Mabedi and the Saltpan are inliers amid the younger rock.

At the former locality the outcrops form two dome-shaped hills, almost united at their bases, and which are visible from a great distance.

The rock exposed is almost entirely a massive brown, grey, purple, or black chert, highly brecciated and veined with chalcedony and quartz, and never showing any traces of bedding.

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The northern hill, Spits Kop, which rises to a height of about eighty feet, is formed entirely of these rocks, but in the southern hill, on its eastern side, is a narrow belt of fine-grained magnetic slate, with high dips, often contorted, striking a little west of north. On the west side of the hill there are brownish sheared ochreous rocks, more or less quartzose and cherty, containing some carbonate.

At the Saltpan the long ridge west of the pan is composed of cherty rocks, more ferruginous and banded than those on Spits Kop. Towards its south-eastern extremity, immediately behind the Police Camp, there is a great amount of breccia, in which the abundant cementing material is red-brown haematite.

On Wonder Klip there is a wide ridge, composed chiefly of cherty rocks, but magnetic quartzites are also represented, especially on the eastern side, and are useful for indicating the varying dip. On the west side a well at the homestead has been sunk in a gneissic muscovite-granite.

From the main mass at Wonder Klip, a narrow belt, bounded apparently on both sides by thrusts, extends northwards across Papies Vlakte, and then acquires a north-westerly strike; from a distance it resembles one of the dark dolerite ridges of the Karroo.

A little north-west of the homestead on Papies Vlakte, an opening shows beneath the magnetic quartzite a coarse-grained and highly sheared variety of granite.

On Gemsbok Pan the formation makes a high ridge, towards the summit of which, and on the west side, there are numerous trenches and shafts.

The sections show that the formation is very much disturbed. The muscovite granite is highly sheared, and traversed by small quartz veins and stringers. There are alternations of crushed granite, vein quartz, brecciated vein quartz, chert, and magnetic quartzites; in some places the granite has been thrust over the latter, in others it underlies them.

The rocks are much brecciated and silicified, and quartz reefs occur commonly along the fault-planes separating the two formations.

Most of the trenches were excavated in order to lay bare a wide quartz reef, which, I am informed, gave in places fairly high assays.

At the summit of the hill the rocks are well exposed, and the quartzites contain much haematite, as well as magnetite. These massive beds, which are repeatedly folded and contorted, correspond to those seen at the base of the formation at Kraaipan.

While the outcrop extends only a couple of miles north-westwards, the parallel belt, a mile to the east, passes right through the Mosita Native Reserve.

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It is probable that on Groot Gewaggd, where this belt commences, the formation rests normally upon the granite, but northwards the junctions on both east and west sides seem to be faults.

On Mosita the belt consists principally of white grey or black cherts, well banded, and containing thin layers of jasper and beds of magnetic and haematitic quartzites and slates.

The strata, which usually dip vertically and have a strike which does not quite coincide with the direction of the belt, are somewhat folded and traversed by numerous transverse faults.

These fractures, which have usually a throw of not more than a few inches, are quite abundant and arranged close together in step-like fashion, and are often accompanied by minute threads of vein quartz.

On the farm Parnell the formation is absent for some distance, being cut out apparently by the upper thrust plane.

On Moshesh the beds re-appear, and the outcrop rapidly widens, to form a band over a mile wide, and through which the Mosita River has cut its channel diagonally.

The lower beds consist of the usual massive magnetic rocks, which are here rather cherty, and contain thin bands and patches of bright red jasper. On Blik Plaats the beacon on the left bank of the river stands on a wide ridge of these rocks, the great breadth of which is probably due to repeated folding.

The low hills east of the river are formed of massive white or buff cherts and banded translucent, white, grey, black, and jaspery varieties. A most conspicuous rock is a beautifully banded red jasper, often in thick beds and of wonderful brilliancy. It contains ferruginous and translucent layers, and is traversed by veins of quartz.

It is interesting to find in this formation such a development of jasper, hand specimens of which are identical with rocks in the Griqua Town series of Hay, although the two formations differ so greatly in age.

Beyond Blik Plaats the belt was not followed, but it is probable that it extends northwards for many miles further.

IV. *Occurrences between the Central and Western Belts.*

At Maribogo the magnetic rocks form a ridge, U-shaped in plan, opening to the north-west, having its north-eastern side practically coinciding with the Transvaal border.

On this side the strata dip north-eastwards at angles of from 40 to 65 degrees, and possibly the beds may represent the Khunwana extremity of the Kraaipan belt, shifted westwards by means of a transverse fault.

In the angle of the border fence the dip is easterly, the outcrop curves round, and the rocks form a series of black ridges just within the Transvaal.

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The flats are covered with red sandy soil, but there is nothing to negative the supposition that the junction with the granite is an unconformable one.

The massive rocks forming this ridge east of Maribogo correspond to the basal bed so well exposed at Kraaipan, but here, however, actinolite has replaced quartz, sometimes to such an extent as to convert the magnetic quartzite into a magnetite-actinolite rock. These rocks are well banded, and sometimes require careful examination before the ferro-magnesian mineral becomes apparent, as there is no change either in the mode of weathering or in colour.

In some layers the actinolite is so abundant in large crystals over an inch across as to give one the impression that the material is of igneous origin.

These magnetite-actinolite rocks include layers of magnetic quartzite, while further south and south-east, along the strike, the actinolite diminishes rapidly in quantity as a constituent, so that in the south-western ridge the magnetic rocks are essentially quartzitic. These magnetic quartzites are here succeeded by flaggy ferruginous beds, brownish yellow to purplish in colour, sometimes of the nature of a sandstone, and at other times rather cherty. The beds are usually rather ochreous, and contain only a very minute quantity of magnetite. They recall similar rocks at Mosadiapitsi, and probably represent altered phyllites. Cavities now filled with ochre may perhaps at one time have contained crystals of iron carbonate.

In the south-western ridge the rocks all dip to the south-west; nevertheless the granite appears in that direction.

Further, again, at the base of one of the two little hills at the northern end of the ridge there are two wells in horizontally-foliated gneissic granite, towards which the sedimentary rocks are dipping.

No normal system of faulting can explain the nature of the contacts, and it is reasonable to suppose that the magnetic rocks composing the south-western ridge and the two hills to the north form merely cappings on the granite. In several places on the ridges there are overfolds, as well as rapid variations in strike.

The most probable explanation of the structure is that a thrust plane bounding the east side of the north-eastern ridge curves downwards over the latter, and then passing horizontally beneath the cappings of magnetic rocks in the south-western ridges, separates these sediments from the underlying granite. Several smaller discordances can be accounted for by means of the minor thrusts which would accompany this major thrust-plane.

The displacement of the beds from their original position is probably not more than about half a mile in a westerly direction.

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North of Maribogo the same structure seems to occur, but the strata in this case must have been displaced a distance of several miles along the corresponding thrust-plane.

At Setlagoli massive magnetic rocks form a little hill on the left bank of the river. The dips are at high angles to the north and north-east, yet the formation is merely a surface cap, for wells and openings both on the south, south-east, and north show gneissic granite and schists included in the latter.

In the bed of the river, on the north-east side of the hill, there is an exposed surface, about 30 yards in diameter, of granite and gneiss breccia. The rock is intensely hard, and contains fragments of granites, various granitic gneisses, pegmatites, and schists (such as commonly occur in the granite), set in a matrix of mashed up granitic material. The fragments are usually somewhat rounded, and are often over a yard in diameter; whenever they are flattish, there is a tendency for the slabs to be arranged with their flat surfaces nearly horizontal.

Further up the river, and also in the higher ground, the normal granitic gneiss is met with, but about 600 yards downstream, and again about 300 yards further down, horizontal surfaces of similar breccia are well exposed.

I think that this breccia marks the position of the major thrust-plane, upon which the Setlagoli outlier rests; the outcrop seems to pass northwards down the valley for a few miles, for on Latham we find a similar but elongated outlier of magnetic quartzites, trending north and south.

The dips of the strata are as a rule eastward, but in places there is much contortion. Between several layers of magnetic quartzite, and sharply separated from them, there are outcrops of a rock composed almost entirely of pyrophyllite. The exposures are not good enough to see their exact relations, but as the pyrophyllite rock can be traced for over three-quarters of a mile, it possibly represents an original bed in the Kraaipan formation.

On the east side of the outlier the granite, accompanied by aplite and pegmatite, has been thrust over the magnetic quartzites, and now overlies them, the rock being highly crushed and powdered at the contact.

South-east of Doornbult Siding, and almost on the Transvaal border, there rises out of flat ground made of diabase a low ridge, about a mile in length, known as Leeuw Kop.

The magnetic quartzites forming the hill are sometimes cherty, in places recalling characters more prominent in the western than in the central belt.

The strata are folded into a series of small domes and basins, usually not more than one or two hundred yards across, which are finely exhibited at the highest point of the ridge. This structure must have been produced by the crossing of two sets of flexures. The beds are frequently brecciated to a considerable degree.

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About a mile and a half north of this hill there are similar outcrops of magnetic rocks, and a prospecting shaft shows greenish sericitic schist and schistose quartzite apparently underlying them.

There are numerous other occurrences of this formation, but of no great size; the most westerly point where these rocks were noticed is on Zoeteinval, below the quartzites of the Black Reef series.

Folding, Faulting, etc.

Whatever the nature of the magnetic-rocks originally, it is evident that the material contained layers of varying composition, which, as the result of metamorphism, caused the formation of alternating quartzitic and ferruginous bands.

The material was laid down unconformably upon the granite, and then subjected to considerable pressure from some northerly or southerly direction.

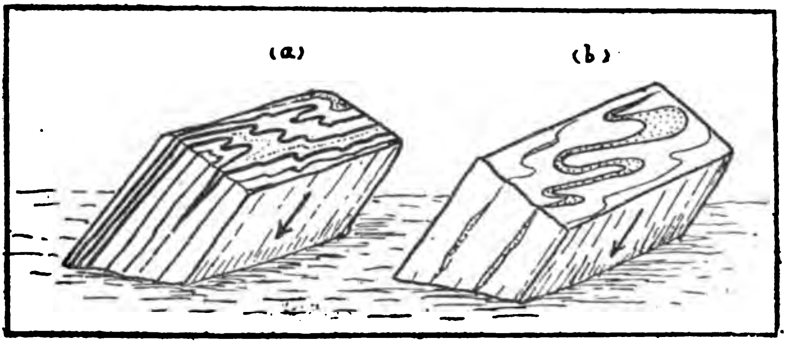

FIG. 3.—Diagrams to indicate the character of the contortions (*a*) of the bedding planes (*b*) of the earlier quartz veins. The arrow shows the direction of dip of the later planes of shearing.

Quartz veins were produced at an early stage, chiefly as thin lenticular layers between the bedding planes, but sometimes crossing them obliquely.

By reason of this pressure, small corrugations were produced, and both the laminae and quartz veins were contorted (fig. 3). In the central belt the strike of these contortions is approximately east and west; the same is the case at Maribogo, but at Leeuw Kop the direction is almost south-east.

These little folds are very often of an isoclinal nature, and their small amplitude and immense number indicate that they were formed while the strata were yet deeply buried.

The slates and quartzites are often traversed by small faults and crushes, while the quartz reefs have been granulitized, and now resemble to a great degree fine-grained quartzites.

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It is interesting to note that the same phenomena have been described from Abelskop,* in the Transvaal.

In connection with these east and west corrugations, it is worth noting that the south end of the Madibi belt shows folds with a similar strike, but with a very much larger amplitude; while on Wodehouse Kraal there are east and west faults, which seem to be older than the eastern thrust-plane.

At a later period the area was compressed from east to west, the strata highly folded, sheared, and cut up by thrust-faults through which portions of the formation were thrust over one another and much displaced; fissures were produced, which were filled by quartz veins.

The earlier wrinklings were to some extent modified by the new pressure, but the effect is seen mostly in the pressing together of the limbs of these minor folds into more or less parallel positions, over which shearing then took place.

The shearing action is shown by the striations which run in the direction of the dip, and by the distortion of the crystals of magnetite. The smaller crystals are unaffected, but the larger individuals have given way along partings parallel to the octahedral faces, and have therefore acquired a laminated structure.

There are seldom any puckerings visible on the faces of these new shear-planes, but the edge of each outcropping bed of rock shows the original contortions (*a*, fig. 3). These planes of shear are only developed in places where the original bedding-planes run parallel and close together for some distance.

For example, in (*a*), fig. 3, the block which is bounded by two such planes will not split directly through the middle, but will fracture with greater facility along the contorted bedding planes.

Thus the apparent bed-planes are in reality surfaces of shearing, but are nevertheless good indicators of the actual dip of the rocks, for their direction coincides with the general direction of the closely folded laminae; nowhere do we find colour bandings and other similar secondary structures crossing the bedding planes.

All the hard beds are more or less traversed by joints parallel to the dip, and the more massive quartzites and hornblendic rocks are divided up into great rectangular blocks.

In the case of the softer rocks, it is probable that the original structures have to a considerable degree been obliterated, yet where the slates alternate with siliceous layers, the superinduced cleavages correspond very closely with the actual bedding.

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* Jorissen, Trans. Geol. S.A., vol. VII., p. 152, 1905; Heneage & Holford, "Notes on the Occurrence of Gold in Primary Formations." Proc. S.A. Assoc. Engineers, 1905.

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Later movements are indicated by belts of more or less brecciated rock, often many yards in width, the angular masses of magnetic quartzite and slate being cemented by brownish chert, chalcedony, or white quartz.

The position of these breccias is commonly independent of the flexures in the strata; they occur quite as frequently in the midst of evenly bedded rocks; the date of their formation has probably to be referred to a comparatively late period, when the strata were but slightly buried and the rocks were too brittle to flow.

The Kraaipan formation must have been enormously denuded prior to the outpourings of the overlying diabase, but the presence east of Kraaipan of quartz reefs traversing this younger formation shows that many of the veins which cut the magnetic rocks may be of a comparatively late date. They are usually composed of barren milky-white quartz.

Auriferous Occurrences in the Kraaipan Formation.

The discovery of gold at Abelskop, in the Transvaal, has given a great impetus to prospecting in the Mafeking Division, and the results obtained at Madibi are most encouraging.

A shaft has been sunk here to a depth of 150 feet, a short distance to the north of the railway and on the eastern side of the belt.

The material passed through consists of a biotite-chlorite schist, which is only found in the fresh condition at a considerable depth. It is always more or less crushed and decomposed, giving rise to white, pink, yellow, greenish, purple, and vermillion-coloured clays, stained with yellow or black limonite, and containing veins and lenses of ferruginous quartz.

This decomposed schist, penetrated by quartz veins, has a markedly well-banded appearance, and forms the auriferous material. It varies in width from three to six feet, and dips practically vertically.

At a depth of 140 feet the unoxidised material was reached, and the vein-stuff is heavily charged with pyrites.

The assays made at first gave very disappointing results, but lower down the values increased rapidly. Portions of the vein-stuff give remarkably high values, while the material elsewhere may carry only a few pennyweights; apparently the gold occurs in chutes.

Some samples taken by the Inspector of Mines, Captain Quentrall, and assayed in the Government Analytical Laboratory by Mr. J. G. Rose, gave an average value of 2 oz. 5 dwt. per ton, over a width of 3 feet 6 inches.

These results are from the variable zone of secondary enrichment. Deeper down, in the sulphide zone, the values will probably become lower, and possibly more uniform.

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The gold has been deposited from solution, together with pyrites and secondary quartz, along lines of fracture and crush. The ore-bodies will in all probability be found to have lenticular shapes, and the veins will pinch and widen both vertically and horizontally.

It would be of immense value, from an economic as well as from a purely geological standpoint, to determine the part played by the schists of the Kraaipan formation in the deposition of the gold. Up to the present, the auriferous occurrences are confined to the schist belts, and the veins in the granite have hitherto proved barren.

It is therefore of extreme importance, from a mining point of view, that the depth of the formation down the fissure to the granite should be known; this demands an accurate knowledge of the geological relations of the two formations.

The possibility that the fissure in the schist belt may become non-auriferous in the underlying granite is one that should not be lost sight of.

Gold has been found in some of the other openings at Madibi, and also at Kraaipan, Wodehouse Kraal, Gemsbok Pan, and on the Khunwana Reserve, in the Transvaal. The values are all low, but perhaps, as at Madibi, the gold content may improve with depth. No reliable records exist of the values obtained at Gemsbok Pan.

The results of prospecting show that, as a rule, the massive beds of magnetic quartzite never carry appreciable values, and the numerous veins of milky-white quartz, both in the formation and in the granite, are practically always barren.

Some of the cherts give values up to 6 dwts., but the rock is very hard and difficult to work in; shafts have been sunk in this material on Wodehouse Kraal. Some of the thin quartzites and earlier granulitised quartz-veins carry gold up to about 4 dwts.

The schists have in places been permeated by mineralising solutions; quartz-veins at Madibi are black with tourmaline inclusions, and minute tourmaline needles are abundantly disseminated through the various schists of that belt. Pyrites is sometimes met with, and is commonly pseudomorphed by limonite.

The softer strata are the ones that will with greater probability be traversed by lines of fracture, and therefore have been impregnated by mineralising solutions. They are, however, badly exposed, but accompany the magnetic quartzites of the central belt, and to a lesser degree those of the western belt.

The only way to test these beds is to cut deep trenches right across the strike of the belts, so as to expose the softer material; although more costly it is, in the end, more satisfactory than sinking numerous pits at haphazard.

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Position of the Kraaipan Formation in the Geological Sequence.

The lithological resemblance of these beds to the rocks known as Barberton beds and Swazi schists has already been remarked. Yet in the Mafeking Division the formation must be later than the granite, whereas in the Eastern Transvaal the granites are said to be intrusive.

According to Jorissen* the same is the case at Abelskop and Goudplaats, in the Bloemhof Division of the Transvaal; the magnetic slates there can hardly be other than part of the Kraaipan formation, but I do not feel quite satisfied that the granite is there intrusive in the formation. No granite veins have been found in the magnetic slates themselves, but only in the amphibolites and calc-chlorite-schists flanking them.

It is always possible, however, that the granite in Bechuanaland does not belong to the same period of intrusion as that in the Transvaal.

In the Prieska Division† of the Cape Colony there are certain magnetic quartzites which are rather different to the type usually met with in the Griqua Town beds. As they occur in the form of belts in the midst of the granite, and have a great resemblance to the magnetic rocks in the Mafeking Division, it is quite likely that they may belong to the Kraaipan formation.

That the Kraaipan formation is distinct from, and much older than, the Witwatersrand formation can hardly be doubted.

The latter is well developed in the Lichtenburg and Klerksdorp‡ Divisions, and is entirely different lithologically, while the alteration in the beds due to earth movements is there but slight, *e.g.*, the development of cleavage and the formation of sericite in the softer beds.

Petrographical Description.

(1) *Ferruginous Rocks.*—The quartzites range from pure white varieties to rocks in which the proportion of magnetite is about 40 per cent. The pure varieties are very rare, and always in very thin layers. The magnetic quartzites range from extremely fine-grained varieties with no visible quartz, to rocks in which the magnetite crystals attain a diameter of over a quarter of an inch. Haematite is commonly associated with the magnetite, but is always subordinate to the latter.

A thin section (1389) of a fine-grained variety exhibits the following features under the microscope:—The quartz-grains are elongated, and show granulitisation. They are usually bordered by brown ferruginous material, and form a matrix in

* Trans. Geol. Soc., S.A., Vol. VII., pp. 152-4, 1905.
† Ann. Rept. Geol. Comm. for 1899, p. 81.
‡ Molengraaff, Trans. Geol. Soc., S.A., Vol. VIII., p. 16, 1905.

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which are set crystals and crystal-aggregates of magnetite and plates of haematite. There are a few grains of corundum.

The varieties with actinolite present many interesting features, and sometimes the amphibole is accompanied by enstatite.

In sections 1390 and 1393 the actinolite is present in smaller amount than the quartz; in 1391 the mineral is more abundant, but in small prisms. In section 1392 the actinolite forms large plates, enclosing ophitically magnetite, haematite, and some quartz.

In the hand specimen these plates attain a length of over an inch. The density of the rock is 3.40. The actinolite is a pale greenish variety, without appreciable pleochroism. This is doubtless due to the abstraction of the iron, which has separated out in the form of limonite along the cleavages and cracks in the mineral. In the thin section 1394 the limonite renders parts of the crystals opaque. The actinolite shows very fine repeated twinning parallel to the orthopinacoid.

Some of the finely-pounded mineral, from which most of the magnetite was separated, gave a specific gravity of 3.01.

The enstatite is pale green in colour, slightly deeper in tint than the actinolite, with which it is often intergrown in parallel positions. In the hand specimen corresponding to 1392, the enstatite is abundant in dark green interlocking grains.

There is no clear indication of the origin of these magnetic rocks. Some of the poorer varieties must have been slightly ferruginous quartzites, but those rich in magnetite may possibly have originated from ferruginous limestones and dolomites.

The actinolite-enstatite-magnetite rocks are rather different in character from the actinolite-grunerite-magnetite rocks of the Lake Superior Region. Laterally they pass into magnetic quartzites; they are not in a region of great disturbance or one of igneous intrusion, and their origin can only be explained by the assumption of a lateral change in character of the original material. This may have been due to variation in the sediment deposited, or to chemical change in certain spots by mineralising solutions, prior to the metamorphism of the material.

Magnetite always predominates over haematite, except in some of the breccias, where the latter forms the cementing material, and where some of the brecciated material has suffered oxidation through the passage of solutions.

(2) *Cherty Rocks.*—Some varieties show clear chert, containing small irregular patches of carbonate, around which granules and flakes of haematite are concentrated. A jaspery variety consists of numerous little oval or slightly irregular bodies, about 0.03 of a millimeter in length, marked out by minute specks of iron ore, and set in a colourless mass of chert.

A section 1387 shows a dense ferruginous rock, which has been cracked in various directions, and the fissures filled in by clear chert. Section 1386 has a small amount of carbonate and flakes of either sericite or talc.

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Some of these cherts carry a little gold.

(3) *Schistose and Slatey Rocks.*—These show gradations from soft silvery micaceous schists through chlorite slates to hard green micaceous quartzites.

Calcareous schists are common along the Madibi belt. A section (1422) from near the beacon K 8 shows large pseudomorphs in pennine (chlorite) after some unknown mineral; these enclose portions of the groundmass. The latter is formed of granulitic quartz, chlorite, calcite, sericite, tourmaline, and abundant rutile, in the form known as sagenite.

Pyrophyllite rock occurs in two forms, either in crystalline aggregates like that already mentioned from Latham (Setlagoli), or massive and slatey, very much like a dark phyllite. The latter was obtained from a prospecting shaft about one-third of a mile north of the main shaft at Madibi.

Chlorite schist, with magnetite, was noted at Latham and a biotite-chlorite-schist at Madibi, the latter forming the casing of the auriferous material. The specific gravity of the latter is 3.12.

(4) *Calcareous Rocks.*—Some of these have been referred to, *e.g.*, the magnesian limestone from near Pitsani and the calcareous schists of Holland and Madibi.

At Pitsani, about a mile west of the Police Camp, is an outcrop of crystalline-limestone, very ochreous in places, and highly veined with calcite and quartz. The thin section (1431) shows large areas of siderite (including flakes of limonite, chlorite, etc.), calcite, quartz, chlorite, and abundant rutile.

The relations of this rock to the adjoining magnetic slates were not seen, owing to the overlying diabase.

A very similar rock was obtained close to the railway at Kraaipan, right in the upper part of the massive bed of magnetic quartzite. The junctions are sharp and irregular, and in the field the crystalline limestone resembles an intrusive mass in the Kraaipan formation. The occurrence may perhaps be explained as an originally lenticular mass of calcareous material, apparently thickened by close folding.

It differs from the Pitsani rock in containing less siderite and chlorite, and in having a feebly developed schistose structure.

V. The Ventersdorp Series.

The name Vaal River System was first and very appropriately applied by Molengraaff* (following Cohen) to the great thickness of volcanic rocks that overlie the Witwatersrand series in the Transvaal, and are older than the Black Reef series. In addition to lavas, they include as well breccias, conglomerates, and other rocks, both of sedimentary and igneous origin, and cover a vast area in the south-western corner of the Transvaal.

* Molengraaff, "Geology of the Transvaal," p. 19, 1904.

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The equivalent term Ventersdorp beds was introduced by Hatch,† in describing the development of this formation in part of the Potchefstroom District.

The name *Ventersdorp Series* has been generally adopted, and will be used throughout this Report.

In the Vryburg Division the Zoetlief beds are separated by a marked unconformity from the overlying diabases and amygdaloids of the Ventersdorp series; still, as they include quartz-porphyries, cherts, grits, etc., very like those described from the latter formation, it seems preferable to group the two formations together, rather than raise the Zoetlief beds to the rank of an independent series. With them in consequence will also be placed the sandstones and conglomerates of Botman's Poort.

1. *The Zoetlief Beds.*

These rocks form a belt of high ground to the north-west of Vryburg, running from Zoetlief in the north through Klip Fontein. The width of the outcrop is usually from four to five miles.

The lowest beds, which, as a rule, are only exposed in wells, consist of arkoses and thinly bedded quartzites, which rest directly upon the granite.

On the farm Hope Vlei a well has been sunk in horizontally lying greenish quartzites, thinly bedded, and with flakes of brown mica on the bedding-planes; similar material was obtained in a well on the farm Klip Fontein, about a mile to the west.

On Wilde Beest Pan there are outcrops of thin-bedded and fine-grained quartzites, dark grey to buff in colour, which dip at an angle of about five degrees to the south-east. To the north these quartzites are evidently not represented, and on Leeuw Bosch and Kameeldoren there are wells which expose a considerable thickness of arkose and re-constituted granite wash. The material varies from coarse pebbly stuff, with abundant fragments of quartz, to fine white pipe-clay, with the beding planes marked out by scales of brown and white mica.

Some of the intermediate varieties have a remarkable resemblance to the decomposed biotite-gneiss found to the north, and it is only by the finding of bands of finer or coarser material that the clastic nature of the rock becomes apparent.

The junction with the granite is never seen, and the presence of the latter is only made evident through the sinking of wells.

The whole of the formation ends abruptly on Vogel Vlei, and apparently the granite has been brought up against the beds by means of a fault striking north-west.

† Hatch, Trans. Geol. Soc. of S. Africa, Vol. VI., p. 95, 1904.

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At the Saltpan is an area of rocks which evidently belong to the base of this formation. The dip is generally at a low angle to the south, and the beds crop out all round the pan, and also at points within it.

The rocks consist of dark grey or greenish shales and flagstones, with flakes of biotite on the bedding planes; they are beautifully ripple-marked, and show numerous casts of worm-burrows. The flagstones are easily extracted in slabs six feet or more across, and by being placed edgewise in the ground can be utilised in constructing kraals and fences.

On the east side of the pan are coarse greenish felspathic sandstones, while a typical arkose is found in a well a mile and a half north of the Saltpan; the strata and the granite are mostly hidden by red soil or calcareous tufa. The flagstones are succeeded by trachytic lavas and breccias, forming the western boundary of the pan; these are followed by a hard grey quartzite.

The relation of these beds to the ferruginous cherts forming the ridge to the west of the pan is not seen, but it is not improbable that the two formations are separated by a fault having a downthrow to the east.

The middle portion of this formation consists entirely of acid and intermediate lavas: quartz-porphyries (rhyolites), trachytes, and allied rocks. Owing to their ability to resist weathering, the quartz-porphyry forms dome-shaped hills and rounded ridges.

The *quartz-porphyries* vary in colour from light pinkish to greenish-black, and contain blebs of quartz and phenocrysts of orthoclase. On the farm Kameeldoren holocrystalline patches occur in the porphyry.

At Zoetlief the quartz-porphyry passes insensibly into orthoclase-porphyry, a dark green rock, which is characterised by the presence of the orthorhombic pyroxene enstatite.

In slide 1381 parts of the enstatite crystals are still fresh, but in the other sections this constituent is replaced by chlorite and calcite, in 1382 by epidote.

The porphyritic orthoclases are much altered, and in fact most of the specimens show a silicification both of the felspar and the ground mass. A little biotite is sometimes apparent.

Trachytes are not so well represented. They are vesicular or drusy rocks, and are to a great degree silicified.

These rocks were found at O'Reilly's Fontein and at the Saltpan; at the latter locality they are associated with trachytic breccias.

An *andesite* was obtained from a well on O'Reilly's Fontein, and there seems to be a continuous passage upwards from andesite through trachyte to rhyolite (quartz-porphyry) on this farm.

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The thin section (1385) shows a highly vesicular rock, with the cavities lined by quartz and chlorite and filled in with calcite. The felspars are in laths, and enstatite is probably represented by little chlorite pseudomorphs. There is some brownish glass in places and a little magnetite.

The uppermost division consists of a variable series of dark quartzites and flagstones, which grade into cherts.

At Zoetlief, where they reach their maximum development, these quartzites and sandstones are greenish-black in colour, with red and brown streaks of cherty material. In a well 95 feet deep at the homestead there are, in addition, greenish flaggy grits, with flakes of brown mica. To the south they are followed by shales, flagstones, and quartzites, often ripple-marked, dipping at an angle of about five degrees to the south-east. Towards the top of the series is a bed of highly vesicular lava, greenish to buff in colour, and probably trachytic in composition. It is succeeded by similar strata, which are often rather flinty.

The whole formation on Zoetlief is affected by slight flexures, having a trend about north-east, *e.g.*, parallel to the fault on Vogel Vlei.

On the farm Karree Bult, close to the Saltpan Siding, there occurs in the midst of the diabase and amygdaloid a small area of shales and flagstones resembling the rocks at Zoetlief.

Some of the shales are very soft, and are accompanied by thin layers of light-grey limestone.

The quartz-porphyry ridge on Leeuw Rand and Schat Kist is overlain by rocks belonging to this division. On Leeuw Rand a belt of cherty rock about 30 yards wide and 400 yards long intervenes between the quartz-porphyry and the diabase, and has a dip of from 30 to 40 degrees eastwards.

These cherty rocks range from colourless to milky-white, brown, red, and black varieties, sometimes well banded, which grade into hornstone or fine-grained quartzite. Some of the chert contains fragments of quartz-porphyry, and these beds appear to consist principally of acid tuffs and breccias that have been silicified. It has already been noted that the quartz-porphyries and trachytes have also been much silicified, an alteration that extends down almost to the base of the volcanic series. On Leeuw Rand the porphyry is traversed by numerous veins of quartz several inches in width, with a north and south strike, and often extending for no small distance. On Schat Kist the same rock is ramified by veins of chalcedony, from colourless to jasper-red, and mostly vertical.

Probably these represent fissures, up which heated waters carrying silica in solution rose. This is a process that not infrequently marks the period following the cessation of the eruption of acid lavas.

Further to the south on Schat Kist, close to the beacon, the cherty rocks reappear, with a general dip of from 5 to 10 degrees

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eastwards. Owing to their extreme hardness, they form a ridge rising to a fair height above the surrounding flats of diabase.

In the midst of the massive cherts, which are at least 150 feet in thickness, there is a thin stratum of hard green sandstone, from massive to flaggy, and sometimes ripple-marked. It is crowded with little grains of glassy quartz, and when weathered is very ochreous.

North of Mafeking, on the farm Sunnyside, there is a low ridge known as the Signal Hill, which is formed of rocks most conveniently grouped with the Zoetlief beds.

The great bulk of the material consists of flinty rhyolitic and trachytic lavas, with which are associated breccias, tuffs, and conglomerates, often much silicified; there are also dark banded flinty rocks, cherts, cherty breccias, flagstones, and quartzites, the majority of which weather with a light brown or yellow exterior. The dip of the formation varies from 20 to 60 degrees, and the strike is a little west of north.

On the north-west side is much red sand, and probably the strata either rest upon or are faulted down against the granite. The eastern and southern boundary is produced by low ground, and a few well-sections show diabase. The discordance both in dip and strike between the two formations is clearly marked.

Relation of the Zoetlief Beds to the Diabase Formation.

The various outcrops all indicate a considerable unconformity between the two formations.

The Zoetlief beds have been somewhat disturbed and greatly denuded prior to the pouring out of the diabasic lavas. The quartz-porphyry and cherts under denuding influences produced marked ridges, and consequently were not buried by the lavas to the same depth as other horizons of the formation. On Middel Kop a well passed through the diabase into the porphyry. On Vogel Vlei the basic lavas apparently cross from the Zoetlief beds on to the granite without being affected by the fault that separates the two latter formations.

At Schat Kist the veins of quartz and chalcedonic silica which are abundant in the porphyry are wanting in the diabase. The discordance north of Mafeking has already been noticed.

The only place where there is no marked divisional line is at the Saltpan; this is due both to the paucity of outcrops and to the coming together of two sets of vesicular volcanic rocks.

2. The Botman's Poort Sandstones.

South-west of Brussels Siding, at the farm Botman's Poort, on the Transvaal border, there are certain sandstones which partly bridge over the gap between the Zoetlief beds and the diabase. The strata appear to form a dome a few miles in

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diameter, situated almost entirely in Transvaal territory. The rocks dip under the diabase on the north-west at angles of about 30°, and on the south and north at lower angles. Whether these beds are conformable with the overlying diabase is uncertain, and can only be ascertained by an examination of the area over the border. On the north of the farm, however, there are so many small outcrops of quartzite in the diabase and amygdaloid as to lead one to the view that there is an interbedding of igneous and sedimentary material. The sandstones vary from fine-grained varieties, often approaching quartzites, to very coarse-grained arkoses and conglomerates, the material being in some places friable and in others hard. Black quartzites, cherty quartzites, and cherts occur very often, and the beds are in places traversed by quartz veins from thin stringers up to reefs several inches wide.

The arkose and conglomerate occur at the bottom of the (visible) formation, and weather into great rounded masses just like granite. There is an abundance of large quartz-pebbles, masses of slate, and boulders up to four or five inches in length, principally of quartz-porphyry, but granite and quartzite are also present. There must be fully 350 feet of strata visible on this farm, and the actual base of the formation is not seen.

The abundance of quartz-porphyry in the form of pebbles points to the Zoetlief beds as their probable original source, in which case the Botman's Poort sandstones will be later in age than that formation.

Close to Vryburg, on the farm Bernau, there are two patches of sandstone, which may conveniently be grouped with those of Botman's Poort.

The western patch (fig. 4) is about 50 yards across, and the strata dip from 10° to 15° in a direction 30° east of north; the second patch, about 300 yards further to the north-east, has about the same size and a dip similar in amount and direction.

The rock consists of a white or cream-coloured sandstone, soft and sometimes friable, but in places darker in colour and quartzitic. The material can be removed in large blocks; it is almost a free-stone, and has been utilised as a building stone. Round about are exposures of diabase, amygdaloid, and breccia, and the only explanation of the manner of occurrence of these sandstones is that the volcanic rocks rest unconformably upon them.

On the railway about two miles north of Vryburg Station there is an exposure in the midst of the Dwyka boulder-clay of similar sandstones, which are here horizontal. Diabase is seen a few hundred yards further north.

3. *The Diabase Formation.*

In this term is included compact and amygdaloidal diabases, volcanic tuffs and breccias, conglomerates, grits, sandstones, and

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shales. We may therefore in the following account consider separately those rocks that are of igneous and of sedimentary origin respectively.

Distribution.—The formation covers a considerable area to the north and north-east of Vryburg, and is found again to the north, east, and south of Mafeking. The former extension of the formation westwards is indicated by the existence of small outliers between Setlagoli and Mosita, in the Mosita valley, at Mosadiapitsi Kopjes, and at Pitsani. In a southerly direction the formation extends along the Transvaal border into the Taungs district.

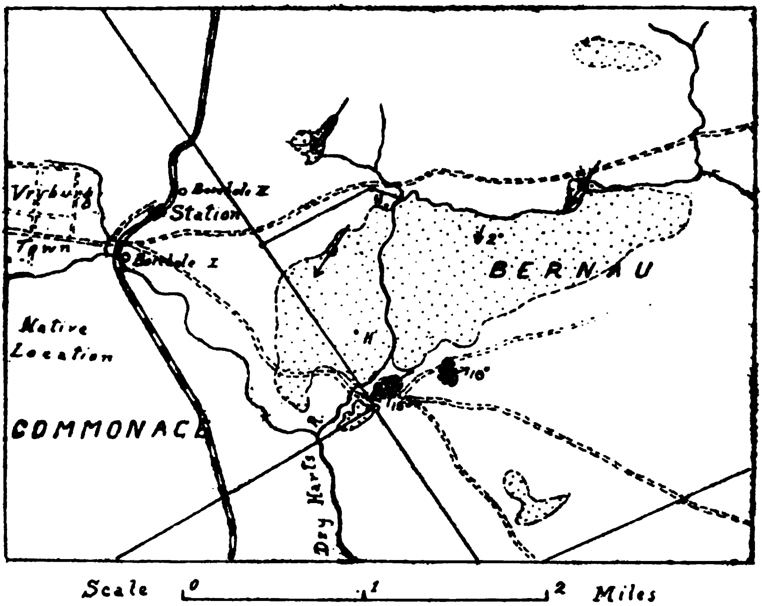

FIG. 4.—Plan showing positions of glaciated surfaces east of Vryburg town. The areas dotted are formed of volcanic rocks, those shaded indicate sandstone, while the unshaded remainder represents Dywka boulder-clay.

(A) *The Volcanic Rocks.*—These constitute the great bulk of the formation, and form wide flats, so that, as a rule, the rocks are not very well exposed.

In the lavas bedding-planes can very seldom be made out. Flow-structures are finely developed, and it is usually uncertain whether the banding, due to rows of elongated vesicles, is to be construed as indicating the actual dip of the bed or merely the lines of flow in that particular stratum. Judging, however, by the frequency with which certain areas are found covered with little knobs of rock, all having the same texture and character, it is probable that in very many cases the dip is approximately coincident with the slope of the surface of the country, *i.e.*, the dips are low.

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The thickness of the formation must be considerable, but no estimates can be made. At Vryburg a borehole (fig. 4, No. II.) was still in diabase at a depth of 531 feet.

The lavas are dull-green rocks, which usually weather with a pinkish or purplish-brown tint. The rock is either compact or vesicular, and the cavities are lined by chlorite or quartz and filled with either agate or chalcedony; the latter is often bright red, like sealing-wax.

In composition the lavas appear to be most frequently andesitic in character, varying from acid to basic varieties, but the rocks are nearly always altered to a considerable degree. Some specimens were glassy lavas, the majority were fine-grained and crystalline, and in one place a porphyritic type was noted.

The felspar is usually the only recognisable mineral constituent; the ferro-magnesian mineral was probably augite, but is usually replaced by chlorite or calcite and epidote. The last named may even be developed in the felspars. The ilmenite is changed to leucoxene. Most of the rocks show silicification to a great degree, and the ground-mass and even the felspar laths are replaced by chert, which polarises as a mosaic.

A rather unusual type of rock occurs on the banks of the Molopo River at the Police Camp, Pitsani.

The lava shows "pillowy-structure," and consists of rounded or ellipsoidal masses, vesicular in the interior, but with dark compact exteriors. They vary from six inches to two feet in length, and are embedded in a dark green igneous ground-mass. The rock passes laterally into very fine-grained diabase and diabase-tuff, and rests upon granitic-gneiss. Further down the river it partly covers magnetic slates.

Another rather unusual type is a variolitic andesite from the farm Faith (Mosita). The thin section (1419) shows a mass of fibres and ragged plates of pale hornblende, commonly arranged in bundles. The ground mass is water-clear felspar.

The diabase-tuffs and breccias commonly form a slight feature in the landscape. Breccias are developed along the river banks on Bernau, just east of Vryburg, and are accompanied by fine-grained tuffs.

The rocks are composed of fragments of diabase of various types, but there has been silicification of the material, and the matrix is chert, with little plates of chlorite and crystals of calcite.

North of Mafeking volcanic breccias form the ridge along the border on Trumpeter's Post, and the formation extends eastwards into the Transvaal. The rock recalls the conglomerates of Mafeking in its mode of weathering, and, like it, includes fragments of granite and gneiss, but not so abundantly. The inclusions consist principally of diabase and amygdaloid, from dark to flinty light-coloured varieties.

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There are numerous transitions, both laterally and vertically, from lavas into breccias. A prospecting shaft shows a peculiar black flinty rock, occasionally vesicular, and evidently originally a glassy lava.

A thin section (1429) of the breccia shows that all the glassy base and sometimes some of the minerals as well has been replaced by chert and rhombohedra of calcite. Fragments of what is now clear chert may originally have been volcanic glass.

The flats to the north are underlain by granite, so that the breccias of Trumpeter's Post apparently rest directly upon that formation.

(B) *The Sedimentary Rocks.*—These occur at two localities, *e.g.*, Mafeking, and between Setlagoli and Mosita.

(i) The Mafeking occurrence has been referred by several observers to the Dwyka conglomerate; a detailed account has been given by Passarge,* while a petrographical description has been supplied by Philippi.†

It seems rather surprising that so many observers should have considered the Mafeking conglomerates to be of Dwyka age, for the soft northern boulder-clay is entirely dissimilar to the extremely hard rock found here; the view that the hardening is due to silicification during Tertiary times is unsupported, as far as I can see, by any field evidence.

The conglomerate forms an outcrop fully three-quarters of a mile in width, upon which the town of Mafeking is built. There are fine exposures in the native stad on the banks of the Molopo. The rocks forms great rounded masses, often many feet in height, between which the native huts have been built.

In the central portion of the outcrop the matrix of the rock is very gritty, and the bedding is well shown; the dips vary from 10 to 20 degrees towards the east. The boulders enclosed sometimes lie with their long axes parallel to the bedding planes, but not always, and they are not arranged in layers according to their sizes.

The actual base of the conglomerate is not seen, but it is underlain by no great thickness of diabase, and that in turn by granite and gneiss, seen in wells, also further down the valley of the Molopo. The conglomerate passes upwards into a rock, which becomes more igneous in character, *i.e.*, a volcanic breccia, and this is succeeded by the diabases and amygdaloids which outcrop south-east of the town.

In a northerly direction the conglomerate belt can be traced for a few miles by occasional boulders in the soil, and the same is the case to the south.

* Passarge, S., Zeits der Gesellschaft für Erdkunde zu Berlin, Band XXXVI., p. 22, 1901.

† Philippi, E., Zeits. der Deutschen Geolog. Gesellschaft, Band LV., Heft IV., p. 314. 1904.

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It is evident that the outcrop represents a lenticular deposit of no very great extent. Estimating from the dips visible, the thickness of rock must be fully 1,000 feet, but it is quite possible that the true inclination of the deposit is not very great, and that the apparent dips represent a kind of false-bedding, for it is hardly likely that coarse conglomerates and volcanic breccias would be spread evenly over any large area.

Petrographical Description.—The inclusions range in size from pebbles up to boulders about a foot in length. As a rule they are well-rounded, but sometimes, though not commonly, the angles are quite sharp; the fragments in the matrix are very frequently angular. The rock is extremely hard, and it is almost impossible to extract the boulders from it. The inclusions consist chiefly of granite and gneiss, various diabases and amygdaloids, quartz, and less frequently grits and hard slates.

In thin section (1426) under the microscope we find angular to rounded grains of these various rocks set in a pale greenish ground-mass of feebly doubly-refracting opaline silica. The silicification has extended through the inclusions, and has especially replaced the glassy base of the diabase; this recalls what has been already noted in the description of the diabase-breccias. The granite, and minerals derived from it, appear to have escaped the alteration. A certain amount of calcite accompanies the silica.

(ii) Between Setlagoli and Mosita is an outlier of the diabase formation showing peculiar features. On Salem, Kgoro, and Zwart Laagte are diabases and a great development of diabase breccias and tuffs, which fill up a basin in the granite; the hill supporting the beacon M. 6 on Bosch Kop is composed of these rocks.

In the valley traversing Massouw and Bosch Kop these volcanic rocks are replaced by coarse greenish sandstones, very hard and conglomeratic in places. The dips are low, usually about 5° north-north-east.

In the north corner of Mooi Plaats there is some high ground composed of similar conglomerates, but the rock is here crowded with pebbles, which, when weathered out, strew the surface of the ground.

Petrographical Description.—While the pebbles in the conglomeratic sandstones of the valley are commonly from six to eight inches in diameter, those on Mooi Plaats may attain a length of eighteen inches. The boulders are usually well smoothed and rounded, but sometimes they are sub-angular.

The nature of the included material varies in different parts of this area, but granite, gneiss, quartz-porphyry, diabase, amygdaloid, quartzite, quartz, and banded cherts, ferruginous rocks, and jaspers are most abundant.

In thin section (1416) the rock shows a great resemblance to the Mafeking conglomerate, but the silicification has not been so complete.

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The bulk of these inclusions have been derived from rocks which are now exposed within a short distance of the basin; for example, the hill known as Vogelstruis Kop, close at hand, is formed of cherts and ferruginous rocks similar to those found as pebbles in the conglomerates; the quartzites and quartz-porphyries are not represented in the immediate neighbourhood.

To the south-west are extensive sand-covered tracts, which I suspect are underlain by granite. On the farm Bosch Kop a borehole put down by the Public Works Department showed quite an unexpected series of beds.

The section reveals 80 feet of dark indurated shale, 20 feet of slightly micaceous shale passing into fine-grained blackish-green quartzite, 106 feet of coarser-grained quartzite with little muscovite flakes, 114 feet of hard black shales, and 48 feet of hard rock—either quartzite or diabase, but no sample of the core was preserved.

Apparently the finer-grained material, which is at least 400 feet thick, occurs towards the bottom of the basin, and is succeeded by the coarser-grained sandstones and conglomerates seen towards the north.

As the dip of the strata is always low, it is difficult to account for the form of this basin as being due to earth movement solely. Round about, on Vogelstruis Kop, Salem, Zwart Laagte, and Rooi Kop, the older rocks are exposed either naturally or in wells, and a patch of diabase is found on the edge of the basin at the north-western corner of Hartebeest Pan.

Either the basin was one with unusually steep sides and deeply excavated, or else it owes its origin to some extent to faults; in the absence of good exposures it is impossible to decide which is the more likely view.

Relations of the Diabase Formation to the Underlying Rocks.

Everywhere a great unconformity is apparent, and the positions of the various outcrops supply us with considerable information as to the conditions under which the formation was produced.

The later earth-movements were never very extensive, and the surface underlying this formation must have possessed to a considerable degree the features that are now still evident.

The formation must have been laid down on a very diversified surface; the rocks of the Kraaipan formation formed the hill-ranges in those days, and in consequence were not buried to the same depth as the other and lower-lying formations. Denudation has removed the diabase from these ridges either partially or completely, while the presence of outliers of diabase in some of the present river valleys, *e.g.*, the Mosita and the Madiban, shows that the ancient topographical features remain but partially modified at the present day.

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It is possible that in places the diabase flows were insufficient to completely bury the ancient ridges—for example, at Zoetein-val, where the Black Reef series rests upon a former elevation composed of granite and magnetic rocks, partially surrounded by diabase lavas. These features may, however, be equally well accounted for by denudation of the diabase preceding the deposition of the Black Reef quartzites.

It seems most likely that the greater portion of the volcanic material was laid down sub-aerially, for there is great variation in the rocks and a general absence of marked bedding both in the lavas, agglomerates, and tuffs.

In certain areas sedimentation appears to have gone on uninterruptedly with the formation of shales, sandstones, and conglomerates; the size and smoothness of the boulders probably indicates river or beach-gravels; some of the pebbles must have been brought from considerable distances. Finally, the area must have been submerged so as to allow of the deposition of the Black Reef series.

The great amount of volcanic breccia and agglomerate met with in places points to the vicinity of volcanic vents, but I have not yet been able to locate anyof these with certainty. There is also a marked absence of dykes from which the lavas may possibly have issued, as in the case of fissure-eruptions. The only diabase dykes yet found differ entirely in petrographical characters.

VI. The Black Reef Series.

The quartzitic rocks lying at the base both of the Campbell Rand and the Malmani dolomite must be the equivalent of the Black Reef series of the Transvaal.

The Black Reef series is essentially a quartzitic formation, and one that in places becomes conglomeratic. The quartzites are often accompanied by slates and flags and by interbedded diabase flows.

Distribution.

(1) *Vryburg.*—Within the area surveyed the Black Reef series has an irregular outcrop, which runs from Massouw's Kop to Vryburg, crosses the Dry Harts River on Rosendal, makes a turn to O'Reilly's Pan, and then curves round and extends southwards to Dry Harts Siding. It forms the north-eastern extremity of the gentle syncline of the north end of the Kaap Plateau. Owing to their hardness, the quartzites form a narrow belt of high ground; just south of O'Reilly's Pan the strata are horizontal, and have produced a wide tableland.

The quartzites are usually light-coloured rocks, commonly false-bedded, and they pass into dark grey or greenish rocks, with scattered pebbles of quartz, chalcedony, etc. Calcareous

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quartzites are sometimes represented, as on the farm Lange Rand near the Dry Harts River.

Flagstones are very common—thinly bedded quartzites, which are sometimes micaceous and often very finely ripple-marked. These may pass into greenish fissile sandstones or shales, which weather deep red along joints and bedding planes, owing to the production of hydrated iron oxides.

Such shales are well exposed in numerous little quarries at the gaol, Vryburg. Worm casts and other markings, probably due to organisms, are occasionally visible.

The conglomerates are rather unevenly distributed, and over large areas they may be unrepresented. The best locality for studying them is at Vryburg, along the ridge on which the Hospital has been built. Usually the pebbles are collected together to form thin bands, never continuous for any distance; just below the hospital there is a bed of conglomerate many feet thick.

The pebbles vary from one to three-quarters of an inch in diameter, but occasionally larger ones are present. The greater number consist of either colourless or milky quartz, but chalcedony and banded agate are abundant, while quartzite, hard slate, banded jasper, and diabase are also found.

It is evident that the Diabase formation has contributed largely to the formation of these deposits, and no doubt the dark green colour of the shales and quartzites is chiefly due to comminuted diabasic material. It must not be overlooked that volcanic ash may to a considerable extent have been incorporated with the sediments.

The conglomerates at Vryburg have been prospected for gold, but unsuccessfully; their gold content is very low, and the pebble beds are irregularly developed and unevenly distributed.

The thickness of the formation varies from about 150 feet to close upon 200 feet.

(2) *Outliers at Zoeteinval and Blink Klip.*—The outlier of Zoeteinval is fully three miles in length, with a rather irregular outline; it forms the highest ground in this area (4,490 feet), and is a point on the watershed from which a number of stream-courses radiate.

The beds are in some places disturbed by small flexures, but as a rule dips are low.

The quartzites are often either ferruginous or cherty, and are traversed by occasional veins of chalcedonic silica carrying pyrites.

In the extreme northerly corner of the farm the quartzites abut against the highly folded magnetic rocks of the Kraaipan formation, and contain small fragments derived from these older beds.

Two small outliers of quartzite occur resting upon amygdaloidal diabase in the valley traversing Blink Klip.

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(3) *Mafeking.*—The Black Reef series just enters from the Transvaal at a point immediately south of Rooigrond; it forms a small portion of the south-western rim of the great basin of the Marico area.

The formation consists of from 30 to 40 feet of coarse quartzite, sometimes conglomeratic with pebbles of quartz and agate, passing into dense black quartzites, weathering to a reddish brown colour. Slaty beds are now and then present. The outcrop is very narrow and inconspicuous, and the beds have a dip of about two degrees to the east.

Relations of the Black Reef Series to the Underlying Formations.

In the Vryburg area there are only three localities where the contact with the underlying diabase can be made out.

At Massouw's Kop, where the strata are admirably exposed, the quartzites rest upon a slightly undulating surface of diabase, but the latter appears to be perfectly conformable as regards dip with the former.

On Bernau the two formations have the same dip, though the actual junction is hidden.

On Schat Kist and on Lange Rand the quartzites again rest on the diabase, but the dip of the latter cannot be made out.

At Zoeteinval the Black Reef series rests upon three formations, *i.e.*, the granite and gneiss, the magnetic quartzites and cherts of the Kraaipan formation, and the diabase.

At Mafeking the diabases and the quartzites have the same easterly dip.

Volcanic Activity during the Deposition of the Series.

At Vryburg just behind the gaol there is interbedded in the quartzites and shales a flow of diabase about 8 or 10 feet thick, and amygdaloidal in places.

In the gorge of the Dry Harts River, on the farm Rosendal, a sheet of diabase from 10 to 15 feet thick occurs on a horizon about 40 feet below the summit of the quartzites, and can be followed away from the river for some distance. Though usually a compact rock, it is amygdaloidal towards its upper limit, and the junction with the overlying quartzite is exposed on the left bank of the river.

The Black Reef series is always succeeded by a sheet of volcanic material from 70 to 100 feet in thickness, followed immediately by the dolomite.

This is well exposed on Zand Vlakte along the road from Vryburg to Genesa, the rock being highly amygdaloidal.

The best section occurs in the Dry Harts River gorge on the farm Waterloo, close to Tiger Kloof Siding; the dip of the beds is from 3° to 5° to the south, *i.e.*, downstream.

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The great bulk of the material consists of a basic lava, often markedly amygdaloidal, and showing elongation of the vesicles and other fluidal structures. In places it is brecciated or may contain fragments of quartzite, diabase, dolomite, chert, etc., passing into an agglomerate; irregular bands of flinty rock traverse the mass in different directions. Some of the flows are more acid than others.

On the left bank of the river there is an irregular bed of dolomite intercalated in the upper portion of the lavas.

The base of the Campbell Rand dolomite rests in a perfectly unaltered condition upon the upper surface of the lavas, but at the junction there is often a layer of red banded chalcedony, up to eighteen inches in thickness, and due to infiltration.

All this points to contemporaneous volcanic action; Mr. Holmes,† however, has maintained that the amygdaloid is a variety of intrusive diabase.

To the west, on the farm Sweet Home, there are extensive exposures of this volcanic sheet.

Immediately to the east of Brussels Siding there are good outcrops of the volcanic rock immediately below the dolomite. The former is in places a breccia, and towards its upper limit has lenticular masses and thin layers of dolomite intercalated, while fissures in the lava and breccia are filled in with similar material; the dolomite is quite unaltered at the contacts. Again on the farm Lange Rand we find on the ridge overlooking the railway another clear section showing the dolomite resting upon a slightly uneven floor of diabase and diabase-breccia.

There can be no doubt that we have had the formation of a series of flows, accompanied by volcanic breccias, during the deposition of the Black Reef series and the Campbell Rand dolomite. That this volcanic action was widespread is shown by the occurrence of beds of similar igneous material at the base of the dolomite on Sweet Valley, to the south-east of Mafeking.

Relation of the Transvaal System to the Ventersdorp Series.

In this area there appears to be an unbroken sequence from the Diabase up to the Dolomite, sedimentation having been contemporaneous with volcanic outbursts.

Whether there is a break at the base of the Black Reef series is not clearly indicated in this district; certainly the diabases have by their denudation contributed largely towards the forming of the overlying rocks.

In the Transvaal an unconformity is clearly marked in several localities, but a brief examination of the geological map of that Colony shows that over its entire western half the Black Reef

† G. G. Holmes, "Geology of a Part of Bechuanaland West of Vryburg." Trans. Geol. Soc., S. A., Vol. VII, p. 131, 1905.

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formation always rests upon rocks belonging to the Ventersdorp series. That such should be the case over such an enormous area shows that the break between the two formations cannot be of very great magnitude; those places where the unconformity is most marked may be of merely local importance. In Vryburg and Mafeking the relation between the two formations is a very intimate one, and further work to the south will be required to decide the exact value of the supposed unconformity

VII. The Campbell Rand Formation.

Only a small portion of the vast area occupied by this formation was examined, comprising therefore the lowest few hundred feet of beds only. The formation consists principally of dolomitic limestones, but there are thin beds of magnesian limestone, calcareous sandstones, quartzites, and shales.

In the Transvaal the formation is termed simply "The Dolomite," but most of the specimens from the Cape Colony effervesce to a greater or less degree with cold dilute hydrochloric acid.

The rock is bedded in layers of a foot or more in thickness, and contains blackish chert in the form of thin bands, lenticles, veins, and concretions which are oval or irregular in outline.

It weathers in the usual way with a rugged deep brown surface, and jagged portions of dolomite and chert project above the surface of the ground. Percolating water has often dissolved away the rock along lines of jointing so that deep fissures result, which are usually filled in from above with soil or calcareous material. Such channels are finely exposed along the railway in the ascent from Brussels Siding to Tiger Kloof.

Oolitic dolomitic limestones are of frequent occurrence, but no traces of organisms can be made out in them; some beds contain small fragments of dolomite, perhaps rolled portions of material in the course of deposition.

At Kameel Fontein, south-west of Vryburg, there are some soft light-coloured calcareous sandstones containing irregular little cherty fragments that much resemble organic remains.

From Warrants Vlakte, west of Vryburg, a specimen of calcareous sandstone shows in thin section (1361) under the microscope little spheres of chert that are possibly of organic origin.

VIII. The Dwyka Formation.

Shales and boulder-clay belonging to this formation cover a fairly large area around the town of Vryburg. Patches also occur to the south and south-east of the town. To the north no outliers of this formation were observed, the conglomerates of Mafeking belonging to the Ventersdorp series.

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The rocks of the Dwyka formation are hardly ever naturally exposed, but they are fortunately in many cases revealed by wells and other artificial openings; their presence underground is almost invariably indicated by the number of large boulders foreign to the neighbourhood resting upon the surface of the ground.

The Dwyka "boulder-clay"—it can hardly be termed a conglomerate here—is typically a soft argillaceous material, bluish or greenish when fresh, but commonly, and to a considerable depth, weathered to a brownish clay.

This clay is soft enough to be excavated with pick and shovel, but now and then harder bands are met with having a certain amount of carbonate of lime as cementing material.

The boulder-clay gives a yellowish soil, which is covered over by, and impregnated with, calcareous material.

In two wells within the town of Vryburg a stratum of tough clay was met with quite free from boulders or pebbles, the only inclusions being minute grains of quartz sand.

This bed of clay is beautifully banded in different shades of red, purple, brown and green, but the rock fails to part along the bedding-planes, and breaks with a conchoidal fracture. It is about twelve feet in thickness, is overlain by normal boulder-clay, and rests upon a hard light-grey shale that merges into a very tough bedded conglomerate containing large striated boulders.

Inclusions in the boulder-clay are very numerous, blocks of diabase and amygdaloid being most abundant; after these come granites and gneisses, massive conglomeratic and sheared quartzites, dark grits, diabase-breccias, magnetic quartzites, jaspers, cherts, and dolomitic limestones.

The boulders are often from six to eight feet in length, and are finely striated. The smaller pebbles do not usually show the effects of glaciation quite so well. Possibly many of these inclusions have been derived from rocks at one time *in situ* not very far toward the north-east, and have not in consequence been transported any considerable distance.

East of Vryburg (fig. 4) there are glaciated surfaces, and in several localities smooth and well-rounded hillocks of diabase are exposed in the midst of the boulder-clay.

The directions of these striae vary from S. 35° W. to S. 66° W., thus indicating a general movement of the ice-sheet from north-east to south-west.

At Vryburg the formation covers an area about six miles in diameter, and sends an arm about two and a half miles wide to O'Reilly's Pan, a distance of ten miles in a north-easterly direction. Its southern boundary runs along the base of the Black Reef quartzites, and conceals the junction of that formation with the underlying volcanic rocks.

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The boulder-clay rests in a hollow scooped out of the older rocks: that is, the depression represents a glaciated rock-basin; everywhere to the south there is a barrier of quartzite, though it is just possible that an outlet existed west of the railway, in the dolomite area; in this direction the rocks are concealed by a thick deposit of calcareous tufa. The Dry Harts River runs in a deep gorge, not more than 150 yards wide, cut through quartzites; there seems to be no boulder-clay in this channel, and it is very probable that the present river alone is responsible for the excavation.

The floor of the Vryburg glaciated-basin is apparently very uneven, and in several places it projects through the boulder-clay. All the wells in Vryburg have been sunk in this formation, and though some have attained a depth of 90 feet, in no case has the bed-rock been reached.

Of two borings at the Railway Station, Number II. (fig. 4) passed through 144 feet of shale and boulder clay before penetrating the diabase, while Number I. was still in boulder-clay at 182 feet.

On the farm Gleef two wells have proved at least 50 feet of similar material. Water is fairly abundant in the boulder-clay, and a considerable supply is obtained from it in Vryburg; but the quality of the product is not good, the water being very hard and slightly brackish.

Patches of boulder-clay are met with along the railway between Vryburg and Brussels Siding. South-eastward of Vryburg there is a large grassy flat, extending from Hartlip as far down as Rosenberg, and bounded on the east by the diabase of the Transvaal border and on the west chiefly by quartzites.

On the farm Weltevreden there is a small outcrop of till crowded with boulders, while on the farm Van Vreda Dwaling are two wells in shales; further up the hillslope and just below the trigonometrical beacon a well affords a section through the shales into boulder-clay underlying them.

At Malalaring, on the Transvaal border, there are, in close proximity to the diabase, several wells in soft grey and black shales. A little further south is a low ridge, evidently formed of boulder clay, for the red sandy slopes are strewn with large boulders, chiefly of quartzite, quartz-porphyry, and diabase. Within about 150 yards of the Police Camp there is a sill of Karroo dolerite, at least 50 yards wide across the outcrop, cutting through the boulder-clay in a north-easterly direction. The wide flats of Blaauwbosch Kuil, Borthwick, etc., although no outcrops are visible, are probably underlain by the Dwyka formation.

Another very interesting locality is the Dry Harts valley. This depression is somewhere about two miles in width, and is bounded on either side by ridges of dolomite.

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At Brussels Siding, a well shows black carbonaceous shales, very thinly bedded, while a boring beside it penetrated 165 feet of light and dark shales with bands of clay, followed by boulder-clay down to a depth of 191 feet, without the bed rock being reached. As the sides of the valley rise to a height of at least 150 feet above the plain, it is clear that at one time there must have been material filling up the valley to the depth of over 340 feet.

Further down the valley, on Zamenkomst, there are exposures of shale, while on Lange Rand, about a mile and a half south of De Beers' Halt, there are large ballast pits in horizontally-bedded black shales and nodular-weathering blue-black mudstone, containing fragments of plant remains.

These shales are traversed by a sill of Karroo dolerite, having a north-easterly trend. Along the hillside to the north-east, about a quarter of a mile from the railway, shales are exposed in a well within 12 feet of a cliff of dolomite, and it is clear that, as no fault is present, the shales abut undisturbed against a steep face of older rock.

Along this junction, water charged with calcareous matter, probably from the dolomite, has risen, and the hillside for a distance of half a mile is covered by a thick sheet of calcareous tufa and breccia, enclosing fragments of sandstone, quartzite, dolomite, amygdaloid, etc.

At De Beers' Halt there is a small area of boulder-clay, portions of which are much harder than usual.

It is clear that many of the natural features of the ancient pre-Dwyka land-surface are reproduced in but slightly modified form at the present day.

The boulder-clay is usually found in hollows and depressions, which were formerly glaciated rock-basins, *e.g.*, at Vryburg and O'Reilly's Pan, and several of the courses of the pre-Dwyka drainage system coincide with the present river valleys.

Thus shale and boulder-clay fill in the Dry Harts valley as far northward as Gamabot; the small patch in the midst of the alluvial plain on Weltevreden indicates that the ancient channel probably extended in this direction.

In the same way, the tributary rising on Borthwick flows over a wide area of shales and boulder clay at Van Vreda Dwaling, but, in the narrow poort a couple of miles east of Brussels Siding, a small patch of the latter is visible right at the foot of the dolomite ridge.

Probably the stream draining the flat on the Transvaal border and flowing past Dry Harts Siding also marks the position of an ancient valley.

The patches of boulder-clay on the plateau close to Tiger Kloof indicate that large areas of the Dwyka formation have only recently been stripped off the surface of the dolomite.

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The relation of the shales to the boulder clay is a very intimate one; they overlie the latter, but in a number of places they evidently fill up deep hollows in it, and they may therefore occur on the low ground, while the ridges round about are composed of the boulder deposit. In some places layers of shale occur in the midst of the boulder-clay.

Everything points to the shale being an integral portion of the Dwyka formation.

IX. Intrusive Rocks.

Though of varied types, the intrusions are remarkably few in number.

Hornblende Schist.—A rather wide outcrop occurs on the Piring Spruit, a tributary of the Molopo. The least altered variety is a dark-green rock, with hornblende prisms, visible to the unaided eye, and it occurs on either side of a belt of magnetic quartzites. There is no direct evidence to show whether it is intrusive in the latter or not.

In thin section (1432) the hornblende is seen to be a pale variety in large prisms; the groundmass consists of hornblende needles, abundant prisms of zoisite, water-clear felspar (possibly also quartz), sphene, and rutile.

The freshness and nature of the minerals indicate that the rock has probably been derived by metamorphism from a diabase, and that it has been completely re-crystallised.

This variety passes into a schistose rock, and with it is a small mass of sheared quartz-porphyry.

The intrusion can be traced up along the Molopo River for about a mile, and we then find for a distance of about 200 yards alternations of granitic-gneiss and hornblende-schist.

At the contacts with the granite the intrusion is always very fine-grained and schistose, but a little distance away from them the rock is invariably coarser grained and more massive.

The direction of the foliation agrees with that of the gneiss, and strikes in a north-westerly direction. The intrusion probably took place after the gneiss had partly received its foliated structure, but before the forces that produced the foliation had ceased. It is thus probably older than the magnetic quartzites.

Serpentine.—On the farm Regen Vlakte, west of Setlagoli, is a small outcrop of dark brownish-grey serpentine, at a point about three-quarters of a mile distant from the homestead.

The relation to the surrounding rock (granite) is not seen, but the serpentine is probably intrusive.

A thin section (1409) shows colourless serpentine, containing an abundance of chrysotile and flakes of iron ore; the cracks are also marked out by ferruginous material.

Other portions of the rock contain a certain amount of talc.

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Diabase.—A few dykes of pre-Karroo diabase occur; from their comparative freshness, they are probably later in age than the diabase lavas of the Ventersdorp series.

A thin section (1412) of an intrusion ramifying through the granite on the farm Never Set, in the Maretsani valley, shows a fine-grained rock, with elongated prisms of greenish-brown augite, partly converted into diallage. The groundmass consists of almost fresh felspar, a large amount of quartz, and a little epidote and iron ores.

A thin section (1434) from a dyke crossing the Molopo River just above its junction with the Madibi Spruit, has the following features:—Brownish augite, still fairly fresh, in long prisms; plagioclase felspars, crowded with patches and granules of augite and leucoxene; some quartz and chlorite.

Karroo Dolerites.—Several dykes occur, always recognisable by their freshness. In three of these their age is proved by the fact that they are intrusive in the Dwyka formation. The northernmost dyke noted was one crossing the Molopo River at a point about eight miles west of Mafeking.

In the few sections available, the ophitic structure is not well developed. Augite is partly or wholly altered to diallage, and sometimes to yellow-brown serpentine. A marked feature is the occurrence of patches of micropegmatite.

X. Superficial Deposits.

The underlying rocks are always more or less hidden by superficial deposits, of which the most widely distributed is sand.

(1) *Sand.*—This is usually coarse in character, and of a light yellowish-red or pinkish tint. In a few spots, notably north of the Maretsani River, towards the area entitled "First Railway Grant," the colour is very pale yellow or whitish. Apparently the sand is derived principally from the disintegration of the granite and gneiss of the district, and though it occasionally covers up other formations, it is never found overlying large areas occupied by diabase and dolomite.

Generally it may be taken that the depth of red sand increases as one proceeds northwards, so that the granite and gneiss is hardly ever exposed in that direction, except in river valleys or in wells, while only now and then do the more resistant rocks, such as the magnetic quartzites of the Kraaipan formation, project through it. For example, in the valleys stretching northwards from the watershed at Ennesdeel, Langewerk, etc., there are absolutely no exposures of rock, and the same is the case on the wide flats to the south-west of Pitsani.

On account of the depth of loose sand, it is sometimes impossible to sink wells without supporting their sides by means of timber or metal cribs; examples of such wells are found at Tlakgaming, on the road to Morokwen.

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(2) *Gravels.*—On the north side of the town of Vryburg there are gravels resting upon the soft Dwyka boulder-clay; close to the cemetery, where the material is being excavated, they form a layer from two to three feet in thickness. The pebbles consist chiefly of water-worn brown-weathered quartzites, probably derived from the Black Reef series, and agates from the amygdaloids, set in a matrix of small grains of quartzite, quartz, agate, etc. A few diamonds have been found in this deposit. On the flats to the north, and again to the east and south, patches of these gravels are found.

On the right bank of the Maretsani River, between Buck Reef and Harding, there are thick layers of gravels, fully 100 feet above the present bed of the river. The pebbles consist principally of ferruginous chert, magnetic slate, and agate.

Between Mafeking and Kliparani there is a flat-topped ridge, on which the trigonometrical beacon K. 14 is placed, and which is capped with gravels. The pebbles, which are principally of quartz and ferruginous chert, form a thick layer, and strew the hillsides for quite a distance from the crest of the ridge—right down almost to the bed of the Methlonyane Spruit.

The height of this gravel-covered ridge is fully 200 feet above the present bed of the Molopo, and it is evident that since these gravels were deposited, there has been considerable erosion in this part of South Africa.

(3) *Calcareous Tufa.*—This covers a large area, especially in the dolomite region, and to a lesser degree in that occupied by diabase and amygdaloid. It has evidently been produced by the rising through capillary action, and the subsequent evaporation, of water charged with carbonates derived from the underlying rock.

West of Mafeking, along the Molopo River, and to the north in the valley of the Mogasani River, there are large areas of granite and gneiss covered with tufa. It is most probable that the deposit has been laid down from water highly charged with the carbonates derived from the great dolomite area in which both of these rivers rise.

The calcareous tufa is usually very pure, often indeed containing but an insignificant amount of quartz, in the form of minute grains.

At Kraaipan there is a deposit of carbonate of lime, in the form of a finely-divided white powder.

These calcareous deposits often pass into breccias through the cementing together of pebbles of agate, quartz, etc. The tufa frequently contains shells of *Pupa* and *Succinea*.

In many places the rock is so firm that it can be used as a building stone, and has the great advantage that, although soft when quarried, it rapidly hardens on exposure to the air.

(4) *Pan Deposits.*—Calcareous tufa often surrounds and forms the bottoms of pans, especially of those situated upon the dolo-

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mite. It is more common, however, to find the pan filled in with a black soil, a mud in the summer time, but when the pan is dry, a loose friable powdery earth, which shrinks and is traversed by wide and deep cracks.

Towards the edge of the pan are commonly small pebbles, chiefly agates from the amygdaloids, while not uncommonly evidences of prehistoric man appear, in the shape of rudely-chipped implements.

Sometimes, but rarely, a quartzite is found forming the floor of a pan; a good example is met with on the farm Water Pan, north-west of Vryburg. A section afforded by a well is as follows: Red sand, calcareous tufa containing shells of mollusca, a thin layer of pebbles, hard green quartzite, and decomposed friable greenish granite. The quartzite shows grains of quartz, set in a fine quartzose and chalcedonic matrix. There are numerous little drusy cavities, either lined with chalcedony and agate, or into which crystals of quartz project. The green colour has evidently been produced by the ferro-magnesian minerals of the decomposed granite.

This quartzite, from its character and mode of occurrence, evidently corresponds to certain varieties of "Pan-sandstone" obtained by Dr. Passarge† from the Northern Kalahari.

XI. Pans.

Pans are very numerous throughout this area, and vary in size from a few yards up to nearly a mile in diameter; as examples of the last, we have O'Reilly's Pan to the north-west of Vryburg, and the Saltpan (Groot Chwaing) due north of that town.

The material found in these pans has been briefly noted above, but the two large pans require special mention on account of their unique character and the light they shed upon the mode of formation of pans in general.

(1) *O'Reilly's Pan* is a vast depression, surrounded by ridges of Black Reef quartzite or Dwyka boulder-clay. The diameter of the area of erosion is about two miles, while the actual pan itself is slightly oval, with a length of about two-thirds of a mile. The outlet of the pan is on the south-west side, at a level of about 40 or 50 feet above the pan-bottom. The ground on the north and south rises to a height of about 150 feet above the pan, but on the east this is greatly exceeded, owing to the quartz-porphyry ridge of O'Reilly's Fontein and Schat Kist.

The soft Dwyka boulder-clay is the formation in which the pan is excavated; on the west side, and again on the east, there are rounded and smoothed areas of quartzite projecting through the glacial rock. In a few places faintly striated exposures

† E. Kalkowsky. Die Verkieselung der Gesteine in der Nördlichen Kalahari. Mitth. K. Miner. Geol. Museum, Dresden, 1901.

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are found, and it is clear that the outcrops of quartzite are glaciated surfaces. The pan apparently marks the site of an old glaciated rock-basin, and the hollow has been produced by the erosion of the soft boulder-clay.

The bottom of the pan is covered with a friable blackish-grey soil, and a thick mantle of sand of a similar colour forms ridges on the south and south-east side of the pan, obscuring the underlying formations.

The direction of the prevailing wind is from the north or north-west, and it is thus seen that the excavation of the pan has been effected principally by the wind, aided by the disintegrating action of the water, which during nearly half the year covers the pan bottom. The calcareous matter which is blown up with the sand, and which often coats the sand-grains, is the source of the cementing material by which the banks of blown sand are often consolidated.

(2) *The Saltpan (Groot Chwaing)* is a large and irregularly-shaped pan, about three-quarters of a mile across, and but slightly depressed below the general surface of the country.

On the west and south-west runs a ridge of ferruginous cherty rock, while the pan itself is located on the flagstones at the base of Zoetlief Beds (see p. 236). These flags crop out all round the edge of the pan, while irregular ridges of the same break the continuity of the pan-floor.

Curiously enough, an abundance of beautifully fresh water is obtained all round the pan; in fact, wells have been put down on the flat of the pan, a few yards from its edge. Yet everywhere within the pan itself there is a strong supply of brine, which is found at depths of a few feet, even at the end of the dry season. The brine cannot have been derived by leaching from the surrounding country, and must therefore come up along channels and fissures from the underlying rock. In all, the brine-trenches flagstones are exposed, but the granite must exist below them at no great depth.

The temperature of the brine is, I am told, always slightly higher than that of the fresh water in the surrounding wells, and supports the view of the deep-seated origin of the saline material. The brine is very pure, and is not accompanied by gypsum or sodic carbonate.

On the south and south-west sides of the pan there is a ridge covered with blown sand. The floor of the pan is formed of a very light powdery soil, which even a slight breeze is able to carry away.

The brine solution attacks the flagstones, and they become covered with peculiar pittings and hollows like those so well seen in the Malmesbury slates on the sea-shore at Green Point. The flags being highly micaceous and fissile, break up readily, and in this way, by disintegration and wind erosion, the pan is gradually being deepened.

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The sand on the hills south of the pan is charged with salt; this is gradually dissolved out by rain-water, and the saline material returned to the pan. On the east side, there is a considerable extent and thickness of calcareous tufa.

The supply of salt is apparently inexhaustible, and from three to four thousand bags have been removed annually for a number of years.

(3) *Other Pans.*—There are innumerable other pans, but none are much over a quarter of a mile in diameter.

The origin of these is generally uncertain, but, as in most of them the bottoms are covered with friable black earth, it is probable that wind action has played an important role in their formation.

But it is quite as probable that wild animals are responsible for the removal of a great deal of material from such pans, a view propounded both by Mr. Alison* and Dr. Passarge.† In the case of the Saltpan, the influence of wild animals must have been extremely small, while the action of wind is clearly marked.

The evidence in this area shows that it is impossible to propound a single theory to account for the origin and formation of every pan.

* M. S. Alison, On the Origin and Formation of Pans. Trans. Geol. Soc., S.A., Vol. IV., p. 159, 1899.

† S. Passarge. Die Kalahari, Vol. I., chapter 17, pp. 304-317, Berlin, 1904.

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GEOLOGICAL SURVEY

OF THE

DIVISIONS OF TULBAGH, CERES AND WORCESTER.

BY

ERNEST H. L. SCHWARZ.

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GEOLOGICAL SURVEY OF THE DIVISIONS OF TULBAGH, CERES, AND WORCESTER.

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In the First Annual Report of the Geological Commission, published in Cape Town in 1897, there appeared a "Summary of the Work done in the Tulbagh Area and Worcester District"; it was an abstract of a full Report on those districts, which the then Director of the Survey, Dr. G. S. Corstorphine, held over pending confirmation of the points brought together in it; and since then, so continuous has been the exploration of the Colony, and the time for working up results has been so short, that no occasion has offered in which to revise this Report. The present work is an account of the Geology of the districts surveyed by me in 1896, re-written entirely, and considered in the light of the knowledge that we have since acquired.

It must be remembered that when the survey was started, no systematic work had been done in the south-west of the Colony. We had A. G. Bain's map and description, but his results had been questioned by Dunn, Cohen, Moulle, Rubidge, and others, and no one knew which author to follow. It was not in matters of detail that these authors disagreed, but the fundamental division of the rock-systems was in dispute. There are two slate formations—the Malmesbury and Bokkeveld series—and two sandstone formations—the Table Mountain and Witteberg series; were these the same or were they different? That was the question that no one could answer, and no one seemed to be able to find criteria by which to settle the point. Even Dunn, who spent a great deal of time in the field, was unable to distinguish between Bokkeveld and Malmesbury slates, but mapped large areas of the former beds about Caledon as belonging to the latter series, while such a keen geologist as the late Prof. Cohen maintained that the Witteberg sandstones were identical with the Table Mountain sandstone. The whole of the geology had, therefore, to be considered from the beginning. Luckily the district was one in which a final solution of the difficulties could be found, and the conclusions arrived at in this district have been accepted and found correct over the rest of the

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Colony where the same systems occur. Structural points of very great value were also revealed, as well as one of very great economical importance. Put synoptically, the results were:—

1. Establishment of the succession of the rock-systems.
2. Critical description of the beds by which they could be recognised elsewhere.
3. The recognition of the S-shaped bend, a syncline and anticline, as underlying the structure of the mountain ranges.
4. The discovery of the Worcester-Swellendam fault, with a drop of 10,000 feet on the south side.
5. The explanation of the presence of Dwyka and Ecca beds to the south of the folded mountain ranges.
6. The discovery of many new species of fossils.
7. The confirmation of the glacial origin of the Dwyka conglomerate.

The point of economic interest is worth emphasising, as so many look to geological survey work as having no direct value. Dunn had stated that the Karroo beds lay in a basin, and that at their base there was a bed of carbonaceous shales. He had traced this bed outcropping along the Orange River, down along the west side of the Karroo, and then eastwards north of the Zwartberg mountains. He had argued that, though the rock at the outcrop was poor in carbonaceous matter, nevertheless, as the rock had been deposited in a basin, it was reasonable to suppose that there had been an accumulation of organic matter in the deeper parts of the basin, and that, in consequence, there would be vast deposits of coal underlying the central Karroo. The discovery of Ecca and Dwyka beds south of the folded mountains, containing a carbonaceous bed identical in composition with that of the beds north of the mountains, proved that the southern rim of the Karroo basin, when it was originally formed, lay far to the south of where Dunn had supposed it to lie, and that the outcrop along the Zwartberg Mountains, instead of representing the impoverished external rim of the coal beds, was actually the strata in the centre of the basin brought to the surface by the folding that produced the mountains; and since they were just as poor in the centre as in the rim, it was not reasonable to suppose that they would increase in carbon content in any other part.

I divided my work at the time into two parts; first, I studied the rock systems in their normal condition north of the great Worcester-Swellendam fault, and then I turned to the disturbed area south of the fault, and tried to understand the geology here. The district, however, was not one in which a worker could be given a hundred miles or so to work out in detail, unless there was an adequate description of the leading lines to commence with.

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Commencing the description from the west, we find a range of hills, made of Table Mountain sandstone, extending northwards from the Drakenstein mass. They are known as the Limiet Berg, Eland's Kloof Mountains, Vogel Vley Mountains, Roode Zand Mountains, and the Winter Hoek Mountains. At the southern end, opposite Wellington, the area of sandstone is ten miles wide, but this narrows considerably northwards. The railway line is carried on the western side of the mountains, and strikes through them at their narrowest part by Porterville Road; it then doubles all the way back along their eastern side as far as Worcester, when it doubles back again, and strikes through the second barrier of mountains through the poort of the Hex River.

Taking the first range, we find the sandstone of the Table Mountain series resting on an embankment, as it were, of slates. It is at its simplest at the narrow portion—the Roode Zand Mountains, where it is merely a flat, or slightly undulated mass of strata, crushed, however, longitudinally, so that, seen both in section in the New Kloof and along the length of the range, we see slight puckerings and foldings. Where the old road used to go over the mountains, before the Kloof was made practicable, there is a somewhat complex arrangement of faults, the net result of which is to let in a tongue of slate between the sandstone krantzes; as slate weathers so much more readily than sandstone, the slip of argillaceous beds enabled a road to be cut more easily than could have been done elsewhere.

I am not sure of my geology about here; there must be many more faults than those which are plainly visible, and this is, in effect, what is to be seen everywhere in hills made of Table Mountain sandstone in this region. Where there is a great mass of the rock, the similarity of the beds throughout the whole system makes it impossible to detect slight faults, unless very careful search is made; but here, where the beds have been reduced to little more than a remnant, one sees the faults more plainly.

As we go south from the New Kloof, the area of the sandstone widens, and gradually the S-shaped fold begins to develop itself. At the New Kloof we have the remnant of the syncline; further south the anticline is added, and we have the two great kloofs, Bain's Kloof and Slang Hoek, cut more or less in the axes, the one of the syncline, the other of the anticline. The edge of the latter where it should dip under Bokkeveld beds is hidden by enormous accumulations of boulders, formed of Table Mountain quartzite (Fig. 1), and the nearest rock that one can see is the Malmesbury beds, so that there is evidently a fault here. We shall see presently that this fault increases rapidly in intensity, and at Worcester lets down rocks on the south side quite 10,000 feet. Beyond Slang Hoek there is a great knot of

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mountains of Table Mountain sandstone, and formed by the schaarung, or meeting of the north-south and east-west systems of rock folds.

FIG. 1.—Eastern end of Bain's Kloof, showing the nature of the Table Mountain sandstone boundary, and the hiding of all rocks in the valley by deposits of the Breede River.

To the north of New Kloof, the sandstone area also enlarges and joins up with the mass in the Winterhoek, which is part of the second range of mountains. In this way there is formed in the Tulbagh valley a cul-de-sac of Malmesbury beds, surrounded by high mountains of Table Mountain sandstone.

THE MALMESBURY BEDS.

The Malmesbury beds in the Tulbagh valley strike north and south, with variations up to 10° either side; while abnormal dips at right angles to the general strike are not uncommon, the dip is usually to the west from 60° to 80°.

The rocks are much sheared, silvery-grey phyllites, with bedding-planes apparently the same as the shear planes; intense crumpling in places, and occasionally sandy beds and green mudstones. On the Roode Zand Mountains' side there are many quartz veins running parallel to the range. On the Witzenberg side the junction of the Malmesbury beds with the Table Mountain sandstone is very remarkable, and at one time I thought there was an actual conformity. At Schalken Bosch Kloof, for instance, the Malmesbury slates distinctly dip under the sandstone beds at precisely the same angle as the latter strata make with the horizon, and to add to the confusion, the base of the younger series is made up of purple shaley and gritty beds, with quartzite interbedded. The whole section, to anyone seeing

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this section alone, would lead him to describe an actual passage from the shaley Malmesbury beds to the sandstones of the Table Mountain series, through a zone in which both varieties alternate. A little to the north, at Tiger Kloof, the unconformity is well exposed, and no doubt can remain as to the true nature of the junction (Fig. 2).

Following the Malmesbury beds south, there is nothing very remarkable to notice till one passes the entrance to Mitchell's Pass, and the Table Mountain sandstone strikes away to the east. At Eendracht there is a great bed of white quartzite in the slates, accompanied by a thinner band a little way away. Nearing Worcester, there are other varieties, which made me think of

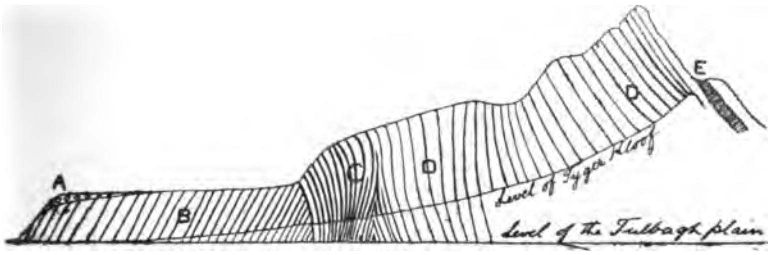

FIG. 2.—Section of the Tulbagh side of the Witzenbergen, showing the junction of the Malmesbury and Table Mountain beds. A, covering of gravel on an old river terrace; B, normal Malmesbury clay-slates; C, grits, quartzites and purple slates with ottrelite; D, normal sandstones of the Table Mountain series; E, upper shale band.

the Barberton beds in the Transvaal. North of Worcester there is a body of white crystalline limestone in the cleaved slates, and many veins of crushed granite. There is probably a mass of granite underlying this portion, for further to the east there are two granite bosses similarly situated; it is from this that I think the dykes have come, and to it is due the development of curious minerals, ottrelite for one, that one finds in the dense, hard, blue-black slates of Brewel's Kloof. Only a short way to the east, the railway cuts through the beds, and all trace of contact metamorphic action has ceased, and we find normal, silvery-grey phyllites, intensely sheared. At Ganze Kraal, however, on the far side of the railway, the ottrelite rocks come in again just under the sandstone.

Still following the Malmesbury beds along the edge of the Table Mountain sandstone, we find that they occupy a narrow strip about a mile wide, and form slatey foot-hills to the rugged mountains. On the south side they are cut off by the great Worcester-Swellendam fault, which I will describe later on.

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The Table Mountain Beds.

The Table Mountain sandstone of the inner range of mountains is exposed better than anywhere else in the Colony. From the north come the lines of the Witzenbergen and Schurftenbergen, prolongations of the Cederbergen, and from the east come the Langebergen. These two lines of mountains meet in a great knot with many puckerings on a gigantic scale, and a sunken area in the embrace of the bend, called the Warm Bokkeveld. The outer range of mountain chains meet similarly, and form a true "schaarung" or streaming of the structural lines; the knot-form of the junction of the inner ranges is perhaps due to the great Worcester-Swellendam fault. The outer ranges do not come within the scope of the present description.

Fig. 3.—The Witzenbergen from the top of the Schurftebergen, showing the steeply inclined Table Mountain sandstone near the head of the Witzenberg Valley, and the shale band at the top of that rock series.

The Witzenbergen and Schurftenbergen are formed respectively by the outer limb of the syncline and the anticline of the S-shaped fold, which, I have already said, forms the basis of all the mountain chains in the folded region. There is no mistaking the fold in this double range, for the syncline for part of its extent bears an outlier of Bokkeveld beds which contain typical fossils. Near Mitchell's Pass, the Bokkeveld beds pinch out, then, to still make clear the S-shaped fold, the Table Mountain series here contains a very well-marked Shale Band (fig. 3),

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which, folded in the particular way, leaves no doubt of the structural formation of the mountains. Elsewhere where we get Table Mountain sandstone intensely folded, so that the limbs of the folds all dip the same way, it is often difficult to distinguish individual bends, as there is no differentiation of the strata, all are sandy; in other words, the Shale Band is not a constant feature of the series.

In the knot of mountains the strata are lying much flatter, and it is difficult to make out the folding. Near the top of Mitchell's Pass the Shale Band is well exposed in the road-cutting, but, unfortunately, here, in the most accessible locality, it is not typically developed, the shales being replaced by argillaceous sandy beds; it is only when one remembers that the

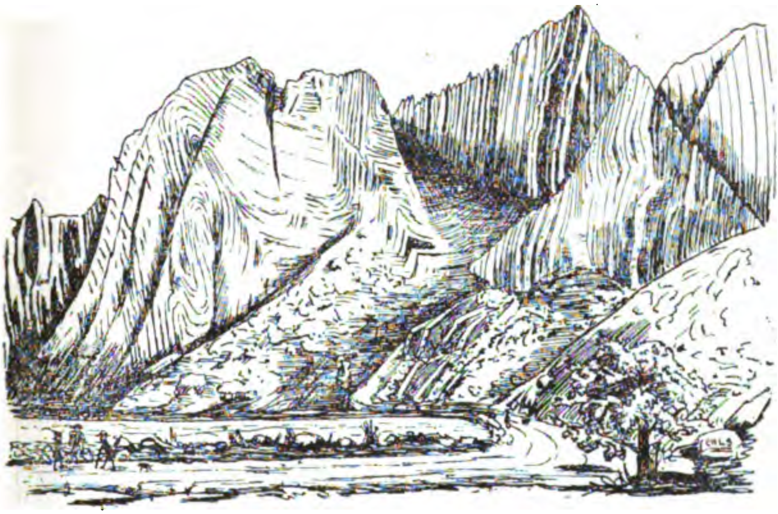

FIG. 4.—Kogman's Kloof, near the entrance of Keur Kloof. Perpendicular and crushed Table Mountain sandstone.

bulk of the Table Mountain series contains no clayey material that the significance of the clayey bed in the road-cutting can be understood. The little argillaceous matter, however, is sufficient to make the soil resulting from its decomposition richer than that derived from the ordinary Table Mountain sandstone, hence the bushes always stand thicker in this belt of rock, and produce a dark line across the mountains.

East of the knot, the Hex River Mountains strike away to the north-east, to culminate in the fine peak Matroosberg. The range is formed by the anticline of the S-shaped fold; the syncline includes the Bokkeveld valley of the Hex River. The outer limb of the syncline strikes a little south of east, and forms the Langebergen, but it is itself broken up by subsidiary folds, which produce hill-ranges of their own. The enormous amount

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of shearing and internal movement which these ranges have undergone is splendidly brought out in the section along Kogman's Kloof, from Ashton to Montagu, a sketch of a part of which I give (fig. 4).. We are, however, not much concerned with the Langebergen in this report.

The Table Mountain sandstone surrounds the Warm Bokkeveld on three sides, the fourth being occupied by hills of sandstone, but of a far younger age, namely, the Gydow or Waagenboom's Mountains, made of Witteberg beds. Many have looked upon the Warm Bokkeveld merely as a quadrangular outlier let down by folds. On the west there are the Schurftenbergen, running in a straight line northwards and exhibiting steep dip-faces of rock. There is an outer series of crests, behind which are the softer beds of the Shale Band, and behind this again are the hills made of the bulk of the rock-series. At places the shale has peeled off the sandstone, leaving enormous slabs of bare rock. This is best seen from Prince Alfred's Hamlets.

If we mount the step from the Warm to the Cold Bokkevelds, and follow the Schurftebergen, we find the outer ridge of hill-crests sinking as it were into the ground, and the Shale Band increasing very greatly in thickness; this is not really the case, for the width of the band is doubled by a sharp anticline (fig. 5). Very fine sections of the Shale Band can be seen just behind the outer ridge of jagged, pinnacled kopjes. The rocks are finely laminated, purple and blue shales, often sufficiently close-grained and consolidated to afford large slabs of only an eighth of an inch in thickness; the rock parts along the bedding planes, but is not sufficiently hard to be used as a roofing slate. I searched these beds most carefully for traces of graptolites or moluscan remains, but unsuccessfully. If we are ever to obtain fossils from the Table Mountain series it is in these beds that they will be found.

The southern border of the Warm Bokkeveld is formed by the great knot of the Hex River Mountains; the inner border of the Table Mountain sandstone is obscured by the river deposits and swamps along the stream beds, but we can plainly see the sandstone dipping under the plain at the foot of the hills. At Ezel Fontein there is a fine little anticlinal ridge projecting at right angles to the mountains, the nose, as it were, cut off by a transverse fault. At Welvaart much the same thing occurs, only the fault, which is parallel to the Ezel Fontein one, cuts off the greater portion of the anticline.

Beyond this point the Hex River Mountains break up into three divergent ridges, each formed of an anticline, and which divide the Warm Bokkeveld into three compartments.

The first forms the ridge over which the old Kimberley road goes, and the kloof which is utilised is called Hottentot's Kloof; it was the last mountain pass before striking into the Karroo

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FIG. 5.—The Cold Bokkeveld, looking across the slate valley or plain, from the Witteberg hills, on the east of the Gydow Pass. The Schurftebergen are seen with an edge of jagged quartzite kopjes; behind this there is a wide belt of slates belonging to the so-called Upper Shale Band. In the right centre the Shale Band is seen repeated by an anticline. On the right, the strike of the beds is suddenly changed; this is on the line of the fault which lets down the Dwyka beds against the Witteberg hills to the east. The farm houses are: on the left, Eland's Fontein; on the right, Molen River.

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on the long, weary journey to the North. The ridge is not made of Table Mountain sandstone on the surface, and were it not for a transverse buckling, which causes anticlines lying across the general direction of the main subsidiary fold to push the sandstone through the Bokkeveld slates, there would be no sandstone at all to be seen.

The tertiary folds, as we can term them—the primary one being the backbone of the Hex River Mountains, the secondary one the buried anticline which carries these tertiary ones as transverse bucklings—are of supreme importance in the study of South African geology. To see the ends of the larger one either on the west, at Leeuwen Fontein, or on the east, at Uitkomst, and to see the sandstone plunging on all sides below the slates, and the Bokkeveld slates, with their tiers of sandstone krantzes, dipping away from the sandstone and conformably to it, making a fine amphitheatre, is to set all doubts at rest about the succession of the series.

There is another interesting point brought out in connection with these tertiary folds. We can often see the actual junction of the Table Mountain sandstone and the slates, and we find that there is frequently a space which is filled in with quartz crystals up to six inches in length and a couple of inches in diameter. This is important in view of the fact that most of the springs in these districts come out in the junction of the Bokkeveld with the Table Mountain series. As we see a definite zone which is occupied with large quartz crystals evidently deposited from solution, the conclusion which we draw from it is that the actual junction of the two systems is the water-bearing zone, and in deep boring this is the horizon that we should strive to strike.

The middle projection of the Hex River Mountains is like a gigantic garden trowel, with the convex side upwards, and stuck slanting into the ground. The culminating peak, Matroosberg, would be where the haft of the trowel joins on to the blade.

The third or easternmost prong of the mountain fork is a long thin anticline, cut off on the north by a vertical fault. On the south side the ground of the plain at the foot of the hills is on a level with the Cold Bokkeveld, but in the north it is on a level with the Warm Bokkeveld; the streams running off the northern face have, therefore, had a far greater fall than those that come off the southern face, and the consequence is that one of them has eaten backwards through the range and has tapped the drainage-supply of the southern high-level flats. The stream cuts across the fault on the north side, and if one walks along the stream bed from Karbonaatjes Kraal on the south side, one suddenly finds the little stream dashing down a vertical wall of some 600 feet in height (Fig. 6). The place where the water falls is not the actual fault line, but is in a recess cut back some hundred yards from the fault, and no more wonderful

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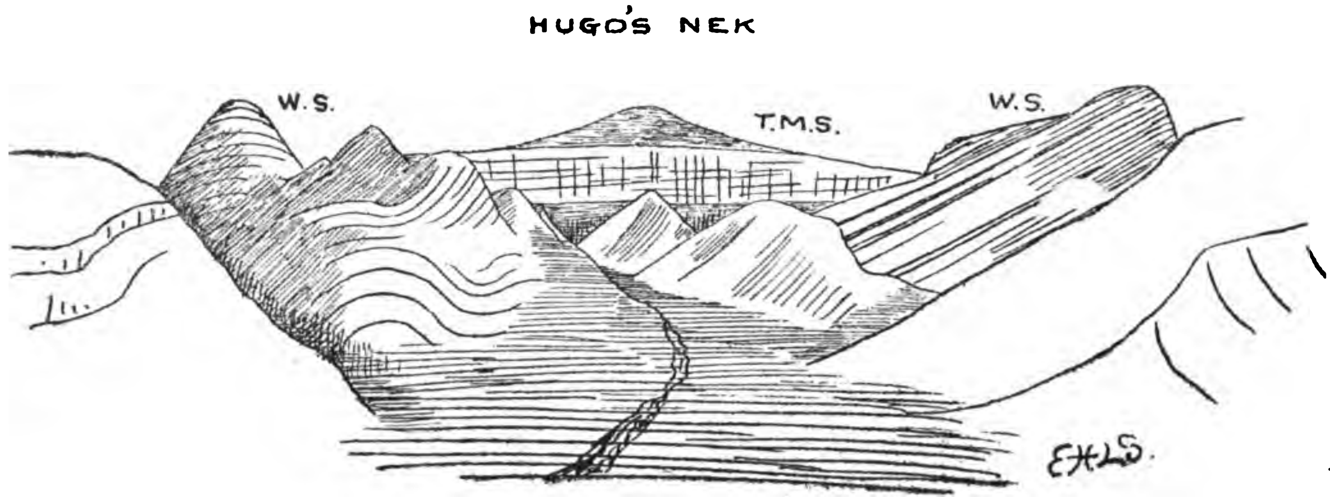

FIG. 6.—Hugo's Nek near Verkerde Vley, showing the fault-face of the Table Mountain sandstone, with inclined beds of Wittebe̶rg quartzite (W.S.) resting against it.

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sight is to be seen in the neighbourhood, which certainly does not lack in grand and beautiful scenery, than in this great recess, and where one can see the sandstone walls towering vertically upwards all round one. The place is called the Kaaiman's Gat.[1]

Turning now to the outer limb of the primary syncline, we find it split also into three portions by secondary and tertiary folds. The most northern of them bounds the Hex River on the south, and the hill-range is called the Kwadouw Mountains. There is a syncline passing diagonally across it which lets down Bokkeveld beds between the nearer and further portion of the secondary anticline, so that the sandstone ridge of the Kwadouw is truncated; the portion beyond the diagonal syncline does not come fully to the surface of the ground, but a series of small anticlinal ridges of sandstone project above the slates of the Bokkeveld series. The middle secondary fold is a narrow anticline that runs to the north of Montagu, and shuts in between itself and the Langebergen, the third of the secondary folds, a remarkable area, known as the Coo and the Kasey. The Langebergen continue for some distance as a single limb of the syncline, but soon broaden out, by smaller bucklings and crushings, and further to the east, increase by the inclusion of a number of isoclinal folds.

The Bokkeveld Beds.

The Bokkeveld beds occur in the synclines of the Table Mountain sandstone, and occupy the following areas:—The Witzenberg valley; the Cold Bokkeveld; the Warm Bokkeveld (three portions); the Baviaan's Berg valley; the Hex River valley; the Coo and the Kasey; and the Brand Vley valley south of Worcester.

The Witzenberg valley is, on the whole, a very narrow band of slates; the northern portion broadens out into a flat plain, but is cut off by a transverse fold, while on the south the slates run up into a narrow trough, and become pinched out. Fossils occur sparingly near the Table Mountain sandstone junction; I obtained on the farm Welgemeend a *Homalonotus* and some fine little *Chonetes setiger*, and a *Spirifer*.

In the Cold Bokkeveld there is very little of the Bokkeveld beds to be seen: the whole of the low-lying country is covered with sandy soil derived, on the one hand, from the hills of Table Mountain sandstone, and, on the other, from the escarpments of the Witteberg beds. The rivers, also, are low grade, being checked at their outflow by hard quartzite banks, so that much of the ground is swampy. At the Gydow Pass there is a drop

[1] Not to be confounded with a place of the same name and very similar in appearance, on the George coast.

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of about 900 feet down to the Warm Bokkeveld, caused by the accumulated effect of several monoclines, with downthrow to the south.

The Warm Bokkeveld has usually been ascribed to the action of running water which had become dammed up by the closure of Mitchell's Pass, and then, when the barrier broke, the water rushed away, leaving a hollow in the hills behind the obstruction. The primary cause of the Warm Bokkeveld, however, is that an area of soft slates has been let down by folding. Water action has played an important part in producing secondary features, for I can recognise a high-level plateau passing over Hottentot's Kloof and the Cold Bokkeveld, and traceable on the top of the Hex River Pass on the other side of the encircling mountains, which was produced by the rivers being checked, and levelling a plain by their meanderings; I can also recognise a

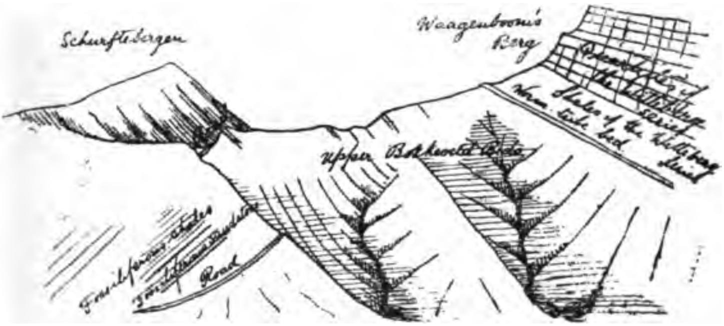

FIG. 7.—View of the Gydow Pass from the bottom, showing the quartzites of the Witteberg series apparently resting unconformably on the Bokkeveld Beds, thus affording grounds for the late Prof. Cohen's view that the Bokkeveld beds were the same as the Malmesbury beds, and the Witteberg quartzites as the Table Mountain quartzites. The reversal of the dip along the road is due to a small fold as explained in the text.

second plateau only a score of feet above the present level of the streams, which is represented by the gravel flats about Prince Alfred's Hamlets. The erosion of the valley has not been due to any stupendous rush of water, but to the slow eating out by normal river action, violent enough indeed when the winter rains set in, and the water rushes down the steep-graded rivulets, but not in the sense of a cataclasm due to the bursting of a high barrier; there has always been a barrier at the entrance to Mitchell's Pass, and it is still obstructing the streams, and it has at one time been eaten away by the rivers more slowly than the tributaries brought detritus, so that an alluvial plain has been formed behind it, but then subsequently the barrier was eroded more quickly, and the alluvial plain cut into by the rivers and removed, without a lake having formed.

A classical place for studying the Bokkeveld series is on the Gydow Pass. On the left as one goes up there is the Table Moun-

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tain sandstone dipping under the slates, and on the right there is the Witteberg beds capping them. The succession is, however, obscured by a monoclinal fold, which traverses the beds diagonally to the face of the escarpment up which the road winds, and this produces reversed dips and duplication of beds (fig. 7). The succession is, therefore, by no means clear. Gydow Pass has always been a prolific hunting place for fossils; near the middle there are some grey micaceous shales, from which large specimens of *Homalonotus herscheli* can be obtained, and a little higher up, to the right of the road, there is a bank of soft, grey-blue shale, stained yellow with iron ochre, full of *Leptocoelia flabellites.* From the same bed as the last I obtained many specimens of another characteristic North American Devonian fossil, *Vitulina pustulosa. Orthothetes sulivani, Spirifer orbignyi, Sp. antarcticus, Ambocoelia umbonata, Retzia adrieni, Centronella silveti, Cryptonella, Rensselaeria, Bellerophon (Bucaniella) trilobatus, Loxonema, Holopea baini, Tentaculites baini, Conularia quichua, Nuculites abbreviatus, N. africanus, Actinopteria eschwegei,** *Modiomorpha baini, and Typhloniscus baini* were all obtained from a mass of material that I dug out in this same face, some of them new species and many new to South Africa.

Following the slopes of the hills below the krantzes of the Gydow mountain, I could obtain no fossils till I came to Hottentot's Kloof, where the Witteberg beds are set back rather sharply. On the level top of the pass there was at the time of my visit a roadside quarry, from which I obtained a large quantity of a peculiar, oyster-like Spirifer, named by Mr. F. R. C. Reed *Spirifer ceres. Ambocoelia umbonata* and *Centronella silveti* also occur in the same bed here.

In the kloof on the eastern side of the Pass some rare Lingulas were found, one resembling *L. densa.*

At Leeuwen Fontein, probably the same farm as Leo Hoek, mentioned by Sharpe, I was unsuccessful in obtaining any fossils, though Bain records from here *Grammysia corrugata, Nuculites ovatus, Palaeoneilo antiqua, Modiomorpha baini,* and *Anodontopsis rudis.* The farm lands are, geologically speaking, remarkably situated. A great rounded anticline of Table Mountain sandstone plunges beneath the slates, and the latter have been eaten away by the action of running water; encircling this bared mass of white sandstone there are three concentric rings of slates, each capped with hard sandstones, and between these hogs' backs and the sandstone lie the farm buildings and gardens. The sandstones I named the Fossiliferous, and the 1st and 2nd White Sandstones, as the first was a blue rock, weathering red, and often full of fossils, whereas the White Sandstones were so strikingly different. Subsequently it has been thought

* This has not been yet recorded from S. Africa; it is a South American form.

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best to re-name these sandstone bands the 1st, 2nd, and 3rd Sandstones, without a qualifying adjective, but it is a little unfortunate, as the Fossiliferous sandstone is calcareous and easily obliterated by shearing, whereas the other sandstones are conspicuously plain in most sections.

To the south the farm Laken Vley adjoins Leeuwen Fontein; here on the south of the long Table Mountain sandstone anticline I obtained a bed almost entirely made up of casts of *Terebratula baini*. A fine tail of *Phacops caffer*, consisting of a black carbonaceous shell embedded in a white micaceous sandy shale, was found near the homestead; this last bed is probably the same as that on Gydow Pass, where the *Homalonotus herscheli* occur in a similar matrix, only that it is greyish instead of being bleached white.

Following the rim of the Warm Bokkeveld to the south there are few good hunting places for fossils; the ground is an elevated plateau, and it is not till one reaches Ezel Fontein, or, as it has once been called, Glen Etive, that one comes on suitable sections. There there is an escarpment somewhat like the Gydow Pass, only not quite so high, and the beds seem much darker, probably on account of the greater steepness of the escarpment and consequent less weathering that has gone on on the surface. The hills to the east of the homestead afforded a great quantity of Nuculites, the species *N. branneri*, *N. africanus*, *N. colonicus*, and *N. martialis*, all coming from here. *Grammysia*, probably *G. chemungensis*, and *Cardiomorpha campestris*, also occurred with a few remains of Trilobites. On the north of the homestead there is a field in which the clayey soil barely covers the yellow shales beneath; every year the plough brings up fresh lumps of rock from below, and in these there are numerous nodules about the size of a man's fist. On breaking these open some beautifully preserved fossils can be obtained; they are mostly casts of the heads and tails of *Homalonotus herscheli*, and what I believe to be another species, or perhaps the female form of the ordinary *H. herscheli*; lamellibranchs are well represented, large perfect casts of *Palaeoneilo rudis*, *P. antiqua*, *P. subantiqua*, and *P. fecunda*; *Bellerophons* and *Tentaculites* are often found in with the larger forms, but no brachiopods turned up. I believe the Fossiliferous sandstone divides the two fossiliferous beds on Ezel Fontein.

North of Ezel Fontein, along the road on Zwar Moed, there is a bed of blue-black sandstone, with a layer of large spirifers at the bottom. Between Ezel Fontein and the village there are a number of spots where fossils may be obtained. At Stink Fontein there is an outcrop of the Fossiliferous sandstone, with a layer of small indeterminate brachiopods in it, and near by in a hard black slate there are some small forms of life, such as *Tentaculites*, *Bellerophon*, and gastropods.

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Close to the village a farmer of the name of Wolvaart had dug a well in some soft greenish micaceous shales, from which a considerable number of fossils have been obtained. They consist of fine crinoids, *Phacops caffer*, *Orthothetes sulivani*, and small lamellibranchs.

In the second compartment of the Warm Bokkeveld, behind Hottentot's Kloof, there is a very fine collecting place on the farm Uitkomst. Starting from the high ground, there are two valleys running down to the farm along the edge of the Table Mountain sandstone ridges (fig. 8).

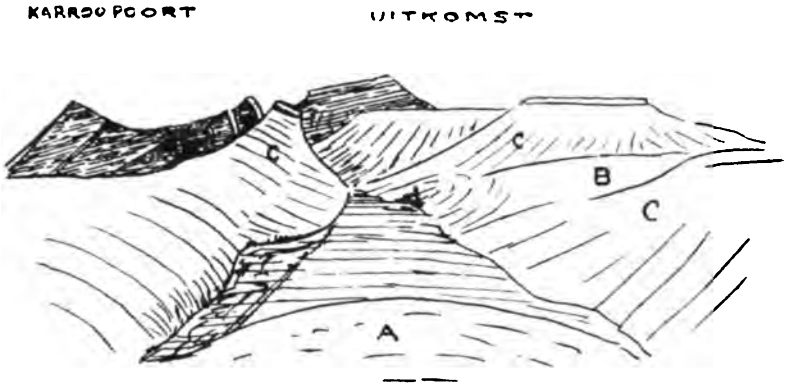

FIG. 8.—Looking towards Uitkomst from the Groen Fontein anticline of Table Mountain sandstone, A. B is the Laken Vley anticline of Table Mountain sandstone. C.C. are slates immediately above the Table Mountain sandstone. The hills in the distance to the left are made of Witteberg beds steeply folded; they were erroneously taken to be the eastern end of the Zwartberg Mountains, hence what we now know as the Witteberg beds were originally called Zwartberg beds.

That on the south afforded almost at the first trial a large nodule composed of yellow clayey material, in which I found on breaking it open a very large Trilobite, named by Mr. P. Lake *Homalonotus colossus*. With the quantity of material obtained at Ezel Fontein before me, I am not sure that the species is different from the ordinary *H. herscheli*; there seems to be nothing of specific value between the larger forms obtained from the nodules at the latter place and this monster from Uitkomst. The blue shales down this part of the kloof are sparingly fossiliferous, and I could only now and again come across an occasional *Leptocoelia flabellites*, *Retzia adrieni*, *Ambocoelia umbonata*, *Conularia undulata*, or *Phacops africanus*, but the isolated specimens were finely preserved. There is in places a thin layer of black harsh slate, stained with pyrites, which contains large quantities of casts of *Orthothetes sulivani*. In the northern valley the same beds occur, but contain very few fossils.

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At the homestead there are literally miles of walling built round the lands, with lumps taken from the bed of Fossiliferous sandstone which covers the hill to the north. Very fine casts of spirifers can be obtained from these walls, and in the rock *in situ*. I found places where the casts showed the internal spiral whorls. The common spirifer is *Sp. antarcticus*, but the allied *Sp. orbignyi* also occurs with *Chonetes coronatus* and joints of crinoid stems.

In the third compartment of the warm Bokkeveld, that which contains the lake or vley called Verkerde Vley, the valley is covered with an accumulation of sand owing to the erosion of the rivers being checked by the hills of Witteberg quartzite, so that the debris cannot be carried away. Under the slopes of Matroosberg, however, on Hartebeest Kraal, some nice Leptocoelias were found, with *Orthothetes sulivani* and *Chonetes falklandicus*.

The Hex River valley is a magnificent syncline, showing on the east side the hogs' backs, formed by tilted shales, capped with hard sandstones. The

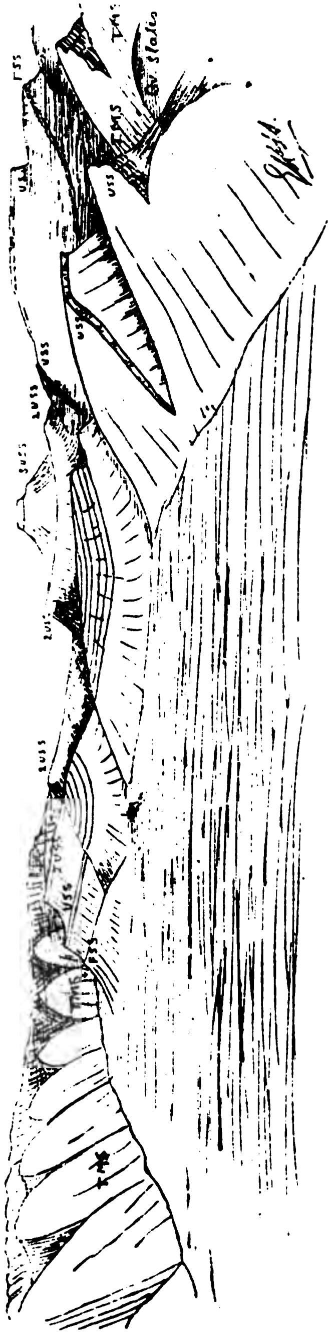

FIG. 9.—View of the Hex River Valley, looking east. In the centre is the Station, De Doorns on the low ground. Behind De Doorns is the August Rug. To the left there is the valley of the Hex River, while the railway turns up the kloof round August Rug. On the left of the picture there are the dip slopes of Table Mountain sandstone under Matroosberg, and on the right, the foot hills of the Quadow's Mountains. T.M.S, Table Mountain sandstone. F.S.S., Fossiliferous sandstone. U.S.S., First Upper or White sandstone. 2.U.S.S. Second Upper sandstone. 3.U.S.S., Third Upper sandstone; these last four sandstones belonging to the Bokkeveld series. Height of De Doorns above sea level, 1,566 feet; Triangle, on top of the plateau behind, is 3,196 feet.

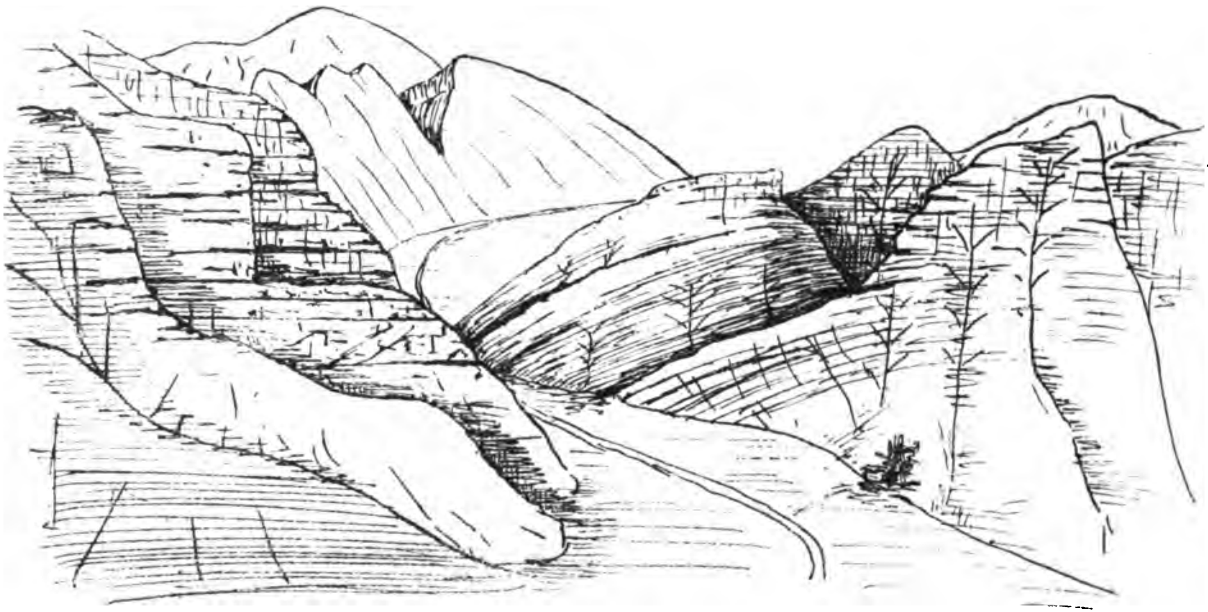

FIG. 10.—The entrance to the Hex River valley from the Worcester side. The peak on the left is Matroosberg; the farm house on the right, Ganze Kraal. The syncline seen in the next figure runs up on the left of the illustration.

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sketches appended (Figs. 9, 10, 11) will show the distribution of the beds better than a written description. The hill to the left of De Doorns has afforded since I was there many fine fossils, such as Phacops, Spirifers, and crinoids, but I did not in this first survey pay much attention to detail; it was in this valley, however, where I first realised that the Bokkeveld series is made up of a definite order of shales and sandstones, which are constant over large areas. The railway after leaving De Doorns climbs up the hills behind by a series of loops and turns, which exhibit the structure of these hills very finely. At Tunnel Siding Mr. Rogers and myself obtained some good lamellibranchs on a subsequent visit.

The valleys of the Coo and the Kasey stand in much the same relation as the Cold and the Warm Bokkevelds, the Kasey being the low ground near Montagu, and the Coo an elevated tract on a level with that at the top of the Hex River Pass; in fact, I regard the Cold Bokkeveld, the top of Hottentot's

Fig. 11.—The axis of the Hex River syncline, pitching upwards at the Worcester end, as seen from Hex River Station.

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Kloof, the plateau on the top of the Hex River Pass, and the Coo as remnants of a plain of denudation which we find further east, covered with river gravels at an average elevation of 3,500 and 4,000 feet. The top of Tafel Berg, in the Hex River valley, shown in the centre of the sketch (fig. 9), probably marks the original level of all these high tracks of Bokkeveld beds, and the plains as they now exist have been lowered some 500-800 feet by processes of denudation. Where the rivers have been active, the plains have been invaded, and low-lying valleys have been produced, like in the Warm Bokkeveld, lower Hex River valley, and the Kasey; but where the rivers have been only moderately graded, the plateau-form has been retained.

The Brand Vley valley is entirely covered with sand, and it is not till one nears Villiersdorp that the underlying Bokkeveld beds appear.

In among the Witteberg hills, to the north of Hottentot's Kloof, there is a valley composed of Bokkeveld beds, the higher zones of which alone are exposed. At Onverwacht I found small fronds of some plant like a liver-wort, with small raised rings, representing a kind of fructification. Mr. Seward, to whom they were submitted, failed to recognise their organic origin, so that nothing can be said further about them.

Taken as a whole, I was unable to find any zoning of the fossils, in spite of a considerable search for them and a careful noting of the horizons. What I found was that the animal remains occur spasmodically in pockets, and that, though most of them occur under the Fossiliferous sandstone, the same species may be distributed throughout the series. Even with the Fossiliferous sandstone, the fossils occur by no means universally, nor do they always represent the same animals; normally it might be called a Spirifer sandstone, but sometimes there are only lamellibranchs and crinoids in it, while again vast stretches are quite barren.

Lithologically there is some difference between the top and bottom of the series, but it is exceedingly difficult to fix on any characteristics; generally, perhaps, one can say that the bottom beds tend to a black, even-grained, mud deposit, whereas the higher are more micaceous and gritty. There is a good deal of pyrites in the form of films colouring the rock, as well as in small wriggling tubules, almond-shaped pockets, and larger nodules; some carbon is occasionally present; these, with a fair proportion of lime, which seems everywhere to impregnate the rocks, both shales and sandstones, rapidly cause disintegration on the surface, and render the original dark blue and black rock a reddish, yellowish, or even white, clay, or sandy shale.

When I was first surveying in the district, there was a great deal of prospecting going on for the purpose of finding oil. The rocks, being full of pyrites, often discolour the water that soaks out after the first rush of rain-water has passed, with iridiscent

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films of polysulphides, very similar to films due to oil. At Ceres itself there is a good deal of vley-ground, once a swampy marsh, but now drained and fit for cultivation; naturally a good deal of decomposed vegetable matter is contained in this soil, and oily substances are continually being given off which likewise give iridescent films. In addition to this, the prospectors found that the American geologists had attributed the formation of oil to the accumulation of organic material in rocks, such as the Marcellus shales, which are equivalent in age, and contain similar fossils, with our Bokkeveld beds. Nowhere in the district, however, did I see any large body of organic remains, nor did I see any porous rocks which could have served for reservoirs, supposing that the organic matter had been decomposed and converted into oil. Reservoirs for water there now exist in between the Table Mountain sandstone and the Bokkeveld beds, the different tensile strengths of the two rocks being sufficient to form cracks, or at any rate, potential cracks, which develop when the rocks are brought near the surface and released from great pressure. Such reservoirs, however, are of vastly younger date than the laying down of the Bokkeveld beds, so that I was reluctantly forced to come to the conclusion that there were no chances for successful boring for oil.

I was strongly of opinion, however, that the Table Mountain sandstone-Bokkeveld junction should be utilised for boring for water, as at one place especially, on the high ground above Uitkomst, I found a definite parting between the two series which was occupied by large quartz crystals, evidently deposited by water that had circulated in the cleft when the particular beds were deep in the ground; also I found that most of the natural springs come up on this junction.

A further description of the Bokkeveld beds as regards their distribution will be found in the last nine volumes of the Annual Report, and a detailed description of the beds will be found in the one for 1899. The fossils are described by Messrs. F. R. C. Reed and P. Lake in the Annals of the South African Museum, Vol. IV., "Descriptions of the Palæontological Material Collected by the Members of the Geological Survey."

THE WITTEBERG BEDS.

The Witteberg beds occur north of Ceres as an escarpment overlooking the Warm Bokkeveld. They consist essentially of hard yellow quartzites in beds of varying thickness, separated by micaceous shales, stained for the most part red. The original rock, both shale and sandstone, is blue, and the extreme result of weathering is a white rock, but on the surface the colours are usually those which I have just mentioned. At the base there is a series of micaceous slates and shales, with a bed of quartzite at the bottom; this latter contains on the Gydow Pass a number of worm tubes, and I tried at the time to fix this bed

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as the definite division of the Bokkeveld and Witteberg series. I found this worm-tube bed at other places, but it has been found impracticable to use it over the whole area of the Witteberg series, whether from want of exposures or absence of the particular bed, so that the separation of the two formations, which I at first thought was fairly easy to make out, has proved to be very difficult and uncertain.

I found in the series some plant stems and indistinct leaves, and there are also some curious bodies represented by casts, very much the same as the *Spirophyton cauda-galli* of the North American Devonian. The plant or sea-weed, for our specimens seem to necessitate the Spirophyton being organic, although Mr. Seward, to whom the specimens were submitted, denies this, grew from a root and then coiled round an axis in the form of a screw, the thallus being thin and wavy, and marked with sickle-shaped ridges. The margin of the thallus is marked by a continuous ridge. The thallus seems to have been very frail and thin, as in the ribbon, green sea-weeds, for the fronds overlap where they have been crinkled and subsequently squeezed by the pressure of the rock. The specimens from root to crown are some six inches high, and the breadth of the topmost whorl, usually about three inches, increases to six and eight inches in loose rock. The extraordinary thing about the Spirophyton is that such a frail organism has been able to stand upright during the sedimentation of coarse sand, for the plant often passes through two or three beds of sandstone, separated by shaley partings. Subsequently Mr. Rogers found a similar organism, only instead of the thallus being a continuous web winding round in a spiral, it is formed by a number of stout rods projecting from an axis, on the same principle as the other species. It is extremely improbable that two similar markings should occur in the same beds, and though so remarkably resembling each other in structure as to make them species of the same genus, that they should be inorganic, yet the ordinary form is classed as inorganic by Mr. Seward, and the rod form is labelled "roots."

The first specimens I obtained were very perfect casts from the Witteberg quartzites east of Brand Vley, but subsequently I found them frequently in the series.

In Ceres the Witteberg beds are very remarkable from the monoclines which traverse them. The rock is very well adapted to show off these small folds by its close bedding and intercalations of red shale between the yellow quartzites, as well as by the resistant nature of the quartzite which allows the faces of the krantzes to remain clear and sharp. Similar ones, no doubt, traverse the Table Mountain sandstone, but the massive banks of the series, unrelieved by differences of composition, and crumbling more readily on the surface, hide any but very large folds; occasionally, as in Kogman's Kloof, where exceptional circumstances obtain, the minor folds are also shown in the older rock system (Fig. 4).

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The monoclines run north-east, and continually bring down the Witteberg series, which is dipping north in places, east in others, with gradations between, in a series of step-faults, for a monocline is merely a fault without break, so that the surface outcrop of the Witteberg beds is far larger than it would be without them, and the apparent thickness of the series is thereby enormously increased. The true thickness of the Witteberg beds is not more than 2,000 feet.

FIG. 12.—The edge of the Gydow Mountains, overlooking the Warm Bokkeveld, with the highest point, on which there is the Trigonometrical beacon, Leeuwen Fontein, in the distance. Two monoclines are shown.

In Ceres there is the Gydow Berg, sometimes called the Waagenboom's Berg, made of the Witteberg series, and from this there is a long stretch, connecting with the mountains that bound the Karroo, the Bontebergen, on the east of Karroo Poort, and the Zwart Ruggens on the north. The outcrop of the beds makes almost a perfect right angle at Karroo Poort, just as the Table Mountain sandstone does by Ceres, that is to say, here the north-south folds meet the east-west folds. It is the interaction of these two simultaneous foldings which produce the "schaarung" or streaming of the structural lines, and the north-east monoclines are parallel to the direction of "schaarung." It is particularly to be noticed that in this case the folds or rock waves butt against each other, and produce divergence, whereas in other folds there may be two series that go on contemporaneously without any reference to each other, and thereby produce cross-folding.

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North of Karroo Poort the Witteberg series is puzzlingly like the Table Mountain sandstone; not only is the sandstone coarser than usual, but there are conglomerates with white quartz pebbles exactly as some parts of the older series. In addition, there is a definite shale-band near the top of the Witteberg beds, which is capped by a series of quartzites in the same proportions as hold good in the Table Mountain sandstone.

In the Witteberg sandstone this shale band is very important economically, for it is the seat of the major portion of the springs that issue from the hills. In the Table Mountain-Bokkeveld couple the seat of the water-parting is actually on the junction; but in the Witteberg-Dwyka couple, it appears in this neighbourhood at least to be behind the outcrop of the junction, some 300 feet below. The best example of this is at Hartnek's

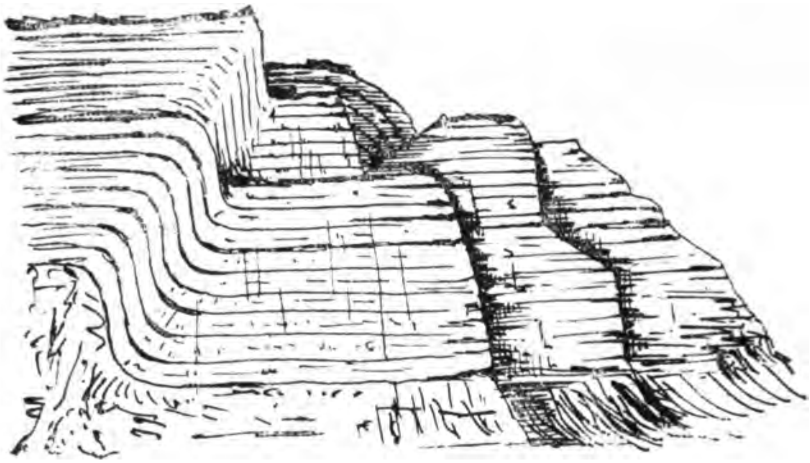

FIG. 13.—Monocline in the Witteberg hills, by Koekfontein, Gydow.

Kloof. The Witteberg dips steeply east, that is, Karroo-wards, from the Zwart Rug, and outside the main dip-slopes there is parallel series of great slabs of quartzite, separated from the former by the shale-band, exactly as occurs in the Table Mountain sandstone in the Schurftebergen, when seen from Prince Alfred's Hamlets. In the Kloof where the road comes down from the mountain, there is a sandy tract, with springs issuing through it. There is a good deal of black and brown sintery deposit from the spring water, with blood red or brilliant yellow patches in it. I was unable to carry a specimen of this material away, as it crumbled to fine dust in my bag, but I am assured that it is purely a deposit of an organic nature, formed by small water plants or possibly bacteria, and that there is no iron in the substance, as the brown sintery appearance would suggest, nor are the bright yellow patches sulphur, as the farmers confidently aver.

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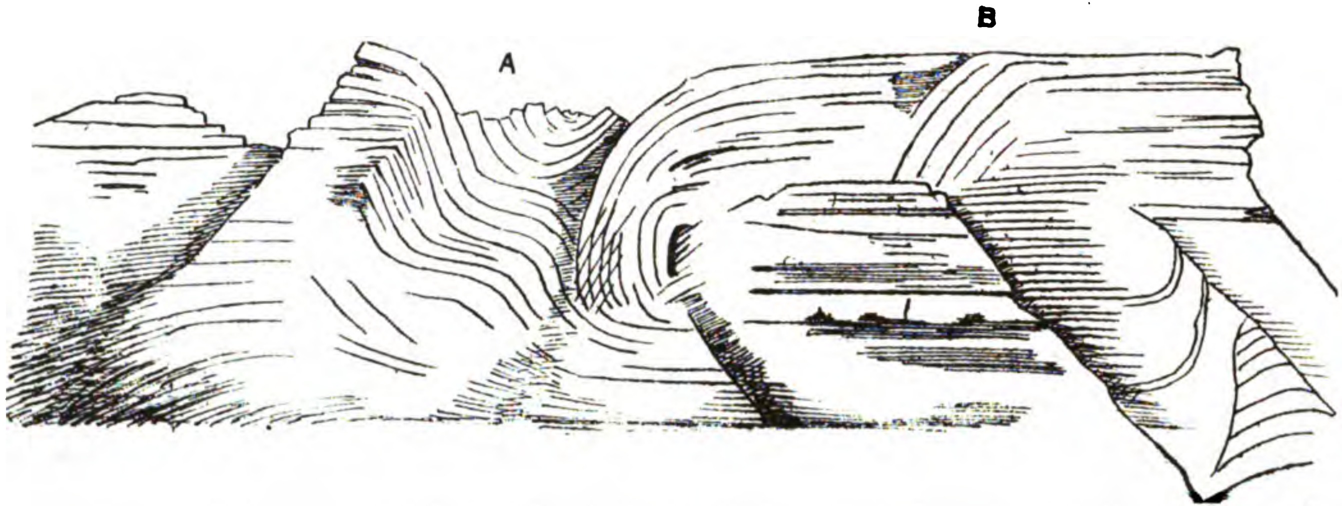

FIG. 14.—Two monoclinal folds, A and B, in Baviaan's Berg, looking from Het Drooge Zand. B goes through the kloof between Grass Berg and Het Drooge Zand's Berg, north of the Trigonometrical beacon. Below A there is a small farm house, with a spring issuing from the hillside. Water is very scarce in these hills.

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South of the Worcester-Swellendam fault there are hills of Witteberg beds, commencing near Brand Vley and passing south towards Villiersdorp, with a valley of Bokkeveld beds between them and the Table Mountain sandstone. They then turn round east along the Bosjesveld Berg, and come up to the fault near Robertson. Near Worcester they form prominent hills, and with their yellows and reds contrast with the grey of the Table Mountain sandstone hills. The presence of such beds near the Malmesbury series was a source of great perplexity, till I found Ecca beds lying against the Malmesbury beds, and I was thus able to explain these as strata that had been dropped by a great fault.

The Dwyka Series.

The Ceres Dwyka beds are of historic interest, as north of the Gydow Berg I found the boulder, which was so typically ice-scratched that the glacial origin of the rock was adopted by the Geological Survey.

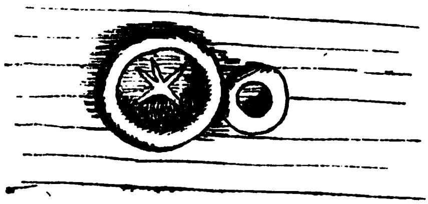

Fig. 15.—Spherical limestone concretions in Dwyka shales. The balls have broken across level with the surface, and the interior has been removed by atmospheric agencies quicker than the harder rind. The cracks produced by the drying of the concreton, now filled with white calcite, are shown.

North of the Gydow Berg the Dwyka beds are enclosed in a horse-shoe of Witteberg hills, closed on the north by an escarpment of Witteberg beds formed by a fault. The Dwyka conglomerate is fairly typical for southern localities, and I obtained most of the varieties of inclusions, such as quartzite, granite, limestone, jasper, and amygdaloid. The shales beneath the conglomerate are hidden by sand, and, in fact, it was not till considerably later that we began to realise the importance of these basement shales, and we did not in the beginning look for them. Passing northwards from Driefontein, the conglomerate is seen to be distinctly bedded; the rock dips at a slight angle northwards, and there are low escarpments with long dip-slopes, where the variation in the hardness of the rock has been brought out in weathering; on a small scale, however, bedding is not noticed, but on the other hand, shear-planes are com-

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mon, probably parallel to the bedding, or what would be the bedding, if there were sufficient variation in the matrix to show this structure. The shear-planes pass through the boulders, and the latter are often minutely and thoroughly broken up into parallel laminae without the matrix showing a corresponding number of planes of cleavage. The boulders thus cleaved are of all natures, amygdaloid and granite being equally affected with the quartzites and jaspers, and the original bedding of the pebbles has no effect on the direction of the cleavage planes.

As one reaches higher beds the boulders become sparser, and there are numbers of rounded calcareous concretions like cannon balls; when broken open, these show star-shaped cracks, filled with calcite (Fig. 15). Sometimes the concretions are simply matrix, cemented with calcareous matter; but again they may be rock with small gravelly inclusions so consolidated.

Higher up in the series one comes to definite shales, which split in long fingers, like the American "hone-stone" formation. The rock is soft shale, and the slabs are an inch or so broad, a half to a quarter of an inch deep, but may be many inches or even feet long. They are produced by close jointing in diagonal directions, one set of joint-planes being very much more numerous than the cross ones. The surface of the beds in these "hone-stones" show pittings which have been attributed to rain drops,* but which may be the effect of "balling" when the mud was soft, that is to say, the particles were aggregated by rolling before being pressed into a continuous mud, and this structure, after the rock had hardened, was preserved, and is now revealed by weathering. Prof. R. B. Young tells me that the muds forming in the lochs of Scotland are sometimes aggregated in this manner.

Outside Karroo Poort the Dwyka is much hidden by sand, and also by an immense amount of calcareous tufa; the latter points to a time when there was greater rainfall in the Karroo and the underground leakage was brought to the surface at the bend in the mountains that close it in. At present there is very little rain; the last that had fallen when I was there was three years previously, and the wells that are put down in the Dwyka conglomerate, though passing through creviced strata, which are filled in with lime deposited by percolating water, are not very successful.

At Beukes Fontein the extraordinary White Band comes in, but better exposures of it were found at a later stage of the survey. Here, however, there is a great development of gypsum, derived from the weathering of the pyritous shale, the sulphur uniting with the surface lime to form the calcium sulphate, or gypsum. The material lies about the hills in large lammelar slabs, like

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*** See illustration of a pencil of this substance with the pitted surface showing, in "An unrecognised agent in the Deformation of rocks," Trans. S.A. Phil. Soc., Vol. XIV., pt. 4, Plate 4, fig. 2.**

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large sheets of mica, but it is only a surface deposit, and is not in sufficient quantity to repay exploiting. Some thin sandy beds are found here, full of indistinct plant stems, and the iron-stone produced by the surface concentration of the iron derived from the decomposition of pyrites, or the pyritous material impregnating the shales, together with the chert, also occur here.

Between Robertson and Worcester, on the south side of the fault, there is a very fine exposure of Dwyka conglomerate, and it is a very extraordinary sight to see all the characters of a Dwyka conglomerate landscape, so typical of the country inside the circling hedge of mountains, reproduced on the south side of these.

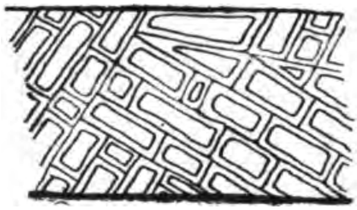

FIG. 16.—Figure showing weathering in upper Dwyka shales; the originally blue rock turns first red, and finally all the iron becomes concentrated along cracks, leaving the interspaces, white and pulverulent.

At Lange Vley the carbonaceous shales at the top of the Dwyka conglomerate have been prospected for coal, but the carbon content never exceeds 10%. The usual curiously coloured shales accompany this, and also the "snuff-box" bed, that is, a shale in which the iron of the binding substance has concentrated along cracks (Fig. 16).

ECCA BEDS.

The Ecca Beds did not come into the survey except south of the fault. It was at Worcester that I first found *Gangamopteris* in shales that I thought were Malmesbury beds, and had always been so mapped by previous geologists. North of the station the rock is unmistakably Malmesbury beds, with inclusions of marble and dykes of crushed granite, but in a quarry near the station there are red, thin-bedded sandstones, lying almost flat, with a slight inclination to the north-east. In among these there are layers of unctuous clay, coloured green with red mottlings, and in a thin bed of these, not more than an inch thick, I obtained many fragmentary kinds of *Gangamopteris* and *Glossopteris*, and small seed-like bodies which Mr. Seward has named *Cardiocarpus*. To the west of Worcester, along the railway line, there are a few kopjes projecting through the immense sheets of alluvium and river boulders. These are made

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up of green sandstones, in which a few fragmentary plant remains may be obtained by patient search, some of which can be identified as *Phyllotheca*.

Towards Robertson the Ecca beds are very strongly developed, and consist of a thick series of shales and sandstones of a prevailing green tint; the vegetation on them is very characteristic, and includes many of the typically African genus of *Cotyledon*, the most extraordinary of which is the boter-boom (butter-tree).

THE UITENHAGE BEDS.

Above the railway cutting at Worcester Station, which gives one an exposure of Ecca beds, there is a red gravel, which belongs to the Cretaceous or Uitenhage series. It is formed of oval pebbles, about the average size of a tennis ball, and is evidently different from the recent gravels and boulder beds of the present river system. The matrix is a dark red clay.

On the east of the line, before it enters the poort in the Table Mountain sandstone hills by Ganze Kraal, there is an exposure of gravel, evidently very old, but of which the pebbles are made of slate. To the south-east of this, across the intervening low ground, there is a similar exposure of gravel near Nuy Siding, on the Cape Central Railway, but here the boulders are of white quartzite, like those of the gravels at Worcester Station, and I am of opinion that both the gravel composed of slate pebbles and that composed of quartzite pebbles are contemporaneous, and that both are Cretaceous in age; the difference in the nature of the boulders being due to the fact that each exposure originally derived its materials from near at hand, and at Ganze Kraal the nearest rock is Malmesbury clay slate, whereas at Worcester and Nuy, the rock is derived from the overhanging mountains of quartzite.

At the time of the survey very little was known about the Uitenhage series, and I could only chronicle at the time that these gravel deposits belonged to a time when the river system was altogether different from what it now is; but subsequently these outliers have been joined up with more extensive ones in Swellendam, Riversdale, and Knsyna, and fossils have been obtained from them which accurately fix their age as Cretaceous.

RECENT DEPOSITS.

The whole Breede River Valley from Tulbagh to Nuy is covered with extensive flats of sand and large rounded boulders of quartzite, derived from the Table Mountain sandstone; how much of this is material recently brought down from the mountains, how much true Enon conglomerate of the Uitenhage series, and how much re-made gravel of Uitenhage

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age, it is impossible to say. Certainly Enon conglomerate does occur in great masses of large white boulders in certain places, and the amount of fresh boulders that is brought down by the mountain torrents is entirely inadequate to explain the enormous quantity of white rounded boulders in the Breede River Valley, so that the weight of evidence seems to point to the rock immediately underlying the Breede River Valley, near Worcester, being part and parcel of the Uitenhage Series.

June 29th, 1905.

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A RAISED BEACH DEPOSIT NEAR KLEIN BRAK RIVER.

BY

A. W. ROGERS.

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A RAISED BEACH DEPOSIT NEAR KLEIN BRAK RIVER.

By A. W. Rogers.

Mr. George Robertson, of Klein Brak River, sent some shells to the South African Museum early in 1905. The shells came from a quarry on his farm, and they were obviously of more or less recent age, though belonging to species that are unfamiliar on the coast of Cape Colony. An opportunity occurred of visiting the spot in March, when Mr. Robertson kindly gave me every facility for examining the locality and obtaining a representative collection of the fossils preserved there.

The accompanying plan shows the position of the deposit and the geological formations in its neighbourhood, but it is certain that the old beach deposits occur elsewhere than in the one locality marked on the map.

A low ridge or terrace rising to a height of about 15 feet above the level of the Klein Brak River vley marks the position of the shelly beds, and small quarries have been opened in the ridge for the purpose of getting out limestone for building. The limestone is a loose textured, rather incoherent rock, but it hardens rapidly on exposure, and appears to stand the weather well. It contains a number of shells, which can easily be removed from the rock.

The following genera and species were recognised by Mr. E. A. Smith, of the British Museum, who kindly examined a collection sent to him:—

Gasteropods:

Turritella carinifera, Lamk.
„ *knysnaensis*, Krauss.
Cerithium, sp. n.sp.?
Natica imperforata, Gray.
Cymatium cretaceum, Lamk.
„ „ var. doliarium, Lamk.
Calliostoma, sp. n.sp.?
Nassa kraussiana, Dunker.
Priotrochus obscurus (Wood.).
Cassis achatina, Lamk.
Bulla ampulla, Linn.
Triton australis.

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Lamillibranchs:

Tapes corrugatus, Gmelin.
„ *deshayesii*, Sowerby.
Diplotodon, near *senegalensis*, Reeve.
Mactra glabrata, Linn.
Venus verrucosa, Linn.
Tellina rosea, Spengler.
Lucina liratula, Sowerby.
Lutraria capensis, Deshayes (narrow form).
Panopaea natalensis, Woodward.
Cryptodon globosus, Forskal.
Ostrea, sp.
„ sp.
Lima rotundata, Sowerby (large form).

All these species, with the exception of the *Cerithium* and *Calliostoma*, are known from the South African seas, though some of them, *e.g.*, *Panopaea natalensis* and *Triton australis*, do not appear to have been recorded from the coasts of Cape Colony. The local distribution of the South African marine mollusca is not well known at present, so that little can be said as to the changes indicated by the above list of shells from Klein Brak River.

Where the river has cut back into these deposits recently the limestone is seen to be underlain by a brown sandy clay, which contains shells, some of which are of the same species as those in the limestone, but they were too fragile from the effect of water to be collected during a short visit.

Both in the clay and in the limestone may specimens of lamellibranchs occur, with both valves intact, and amongst the heavy shells rolled and abraded specimens are not numerous in proportion to the unrolled.

In the limestone I found a piece of quartzite which appears to have been shaped by man. It has a form common to many rude implements of small size found on the surface in various parts of the Colony. Mr. Robertson told me he had found round stones flattened at one end, evidently by use as crushers or pounders, in the limestone.

Pebbles were not of frequent occurrence in the rock exposed at the time of my visit.

The limestone must have been formed at a time when the land stood at least 15 feet lower than now, and when the shore of Mossel Bay passed some two miles inland of its present position.

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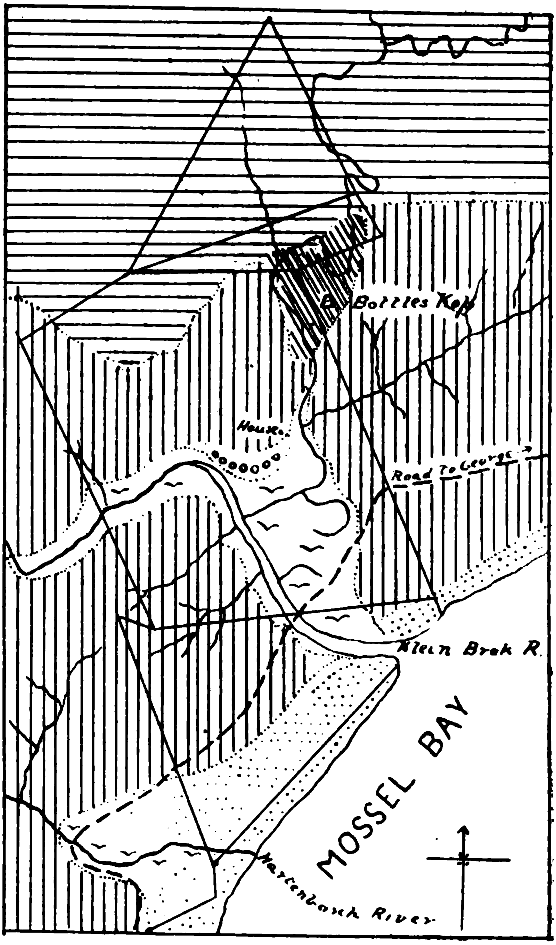

Map showing position of Raised Beach Deposits [oooo] near Klein Brak River

Sand

Alluvium

Uitenhage beds, sands and conglomerates

Table Mtn sandstone ?

Granite.

Formation of a Siliceous Rock on the Surface.

Mr. Robertson drew my attention to a white crust on the surface of bare, dark, clayey ground sloping down to the vley on Klein Brak River. On first looking at it I took it to be a calcareous tufa, such as is found on the surface in parts of the Colony where calcareous rocks lie under the soil, but on breaking it up the interior was found to be dark coloured and transparent at the edges, very much like flint. The thickest layer was about three-quarters of an inch thick. The white colour seems to be due to the loose state of the silica. Under the microscope thin chips of the dark rock are perfectly transparent, and behave between crossed Nicols in the same way as chalcedony.

The specific gravity of the material is 2·56, lower than that of chalcedony, which is given as 2·62 in Mier's "Mineralogy."

Mr. Robertson told me that this crust forms on the surface after wet weather in bare places when these places are undisturbed.

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INDEX.

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CAPE OF GOOD HOPE.

DEPARTMENT OF AGRICULTURE.

ELEVENTH ANNUAL REPORT OF THE GEOLOGICAL COMMISSION.

1906

Presented to both Houses of Parliament by command of His Excellency the Governor.

1907.

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ELEVENTH

Annual Report of the Geological Commission,

1906.

CONTENTS.

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Geological Commission of the Colony of the Cape of Good Hope.

1906.

MEMBERS OF THE COMMISSION.

The Hon. JOHN XAVIER MERRIMAN, M.L.A.

THOMAS MUIR, C.M.G., LL.D., M.A., F.R.S., F.R.S.E.
Superintendent-General of Education.

THOMAS STEWART, M.I.C.E., F.G.S.

WEBSTER BOYLE GORDON, C.I.E., M.I.C.E.

A. H. CORNISH-BOWDEN, Surveyor-General.

Secretary—
THEODORE MACKENZIE.

SCIENTIFIC STAFF.

Director—
ARTHUR WILLIAM ROGERS, M.A., F.G.S.

Geologist—
ALEX. L. DU TOIT, B.A., F.G.S.

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Geological Commission
South African Museum,
Cape Town, 21st February, 1907.

SIR,

I have the honour to forward the Annual Report of the Geological Commission for the year 1906.

Steady progress has been made with the general geological survey of the Colony and additions to the map have been published. It is gratifying to know that in scientific circles the work under the charge of the Commission is much appreciated.

The Commission takes the opportunity of recording its sense of the good work done by the Director, Mr. A. W. Rogers and his assistant Mr. A. L. du Toit, who have displayed the greatest possible interest in the duties committed to them.

A copy of the financial statement duly audited is appended. The Commission have always had in view the financial position and have often felt obliged to curtail expenditure in several directions in which it might have been incurred with advantage.

I have the honour to be,

Sir,

Your obedient Servant,

JOHN X. MERRIMAN,
Chairman Geolog. Comm.

The Hon. the Secretary
for Agriculture.

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GEOLOGICAL COMMISSION.

DIRECTOR'S REPORT FOR THE YEAR 1906.

During the past year only two men have been engaged in field work, but they have had all the necessary means of transport.

The work done was almost entirely confined to the country north of the Orange River. Mr. du Toit worked east of the Kaap Plateau from the northern limit of Taungs down to Hope Town. The chief features in that area are the number of volcanic pipes and the various developments of the Dwyka series. A large amount of information has been obtained on both these subjects. Though it is not possible to carry out such an exhaustive mineralogical and chemical examination of the contents of the pipes as they deserve, the results of Mr. du Toit's field and office work are important additions to previous knowledge. The thanks of the Commission are due to Mr. A. F. Williams, General Manager of De Beers' Consolidated Mines, for the facilities given to Mr. du Toit in his work on the properties belonging to that Company. Considering how frequently the eastern part of Griqualand West has attracted the attention of geologists from the time of the first discovery of diamonds, it is surprising how much new information has been got concerning the geology of the valley of the Vaal River. Some of this ground, however, was very carefully examined by G. W. Stow, in 1874 and 1875, on behalf of the Griqualand West Government,* but his work was never published, and Mr. du Toit has not had the advantage of consulting it. Mr. du Toit's work has made clear the relation of the pre-Karroo sedimentary rocks and lavas exposed in the Kimberley shafts to the similar rocks found elsewhere in Griqualand West.

* "Correspondence . . . on . . . the geological survey of Griqualand West," Parliamentary paper A. 88. Cape Town, 1881.

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My work lay west of the Kaap escarpment. The mapping of the great dolomitic limestone plateau was confined to the immediate neighbourhood of the four routes along which I travelled to and from the Kuruman district. The peculiar nature of the plateau and the number of unoccupied farms combine to make the observer's precise position often difficult to determine without spending more time there than seemed desirable. In general the geology of that area is simple, but the country is traversed by dykes of igneous rocks which are of importance in connection with water supply. The mapping of all these dykes will take a long time, but should be undertaken at no very distant date. The greater part of the work consisted in mapping rocks younger than the Campbell Rand series as far to the west as the Langebergen, and the most important result is the determination of the succession and nature of the rocks forming the Matsap series and their relation to the underlying rocks of the Transvaal system.

No large maps have been drawn for publication in this Annual Report; the reason is that a part of the area described is contained in Sheet No. 45 of the coloured map (3.8 miles to the inch), which will be issued before this Report, and a further large portion of it will be represented on Sheets 42 and 46, which may be expected before the end of the year. It is thought that under these circumstances the time which would be occupied in drawing up maps for this Report and the money required for their reproduction might be saved.

During the present year the survey will be carried on in country adjoining that mapped last year, and it is hoped that almost the whole area enclosed by the Molopo, Orange River, and the O.R.C. boundary will be completed at the end of this year.

The first coloured sheet issued apart from the Annual Reports was published in August last; two more have since been issued, and a fourth is nearly ready. These maps are on the scale of 1 inch to 1,600 Cape roods or 1 : 238,000. This scale will be adhered to for the

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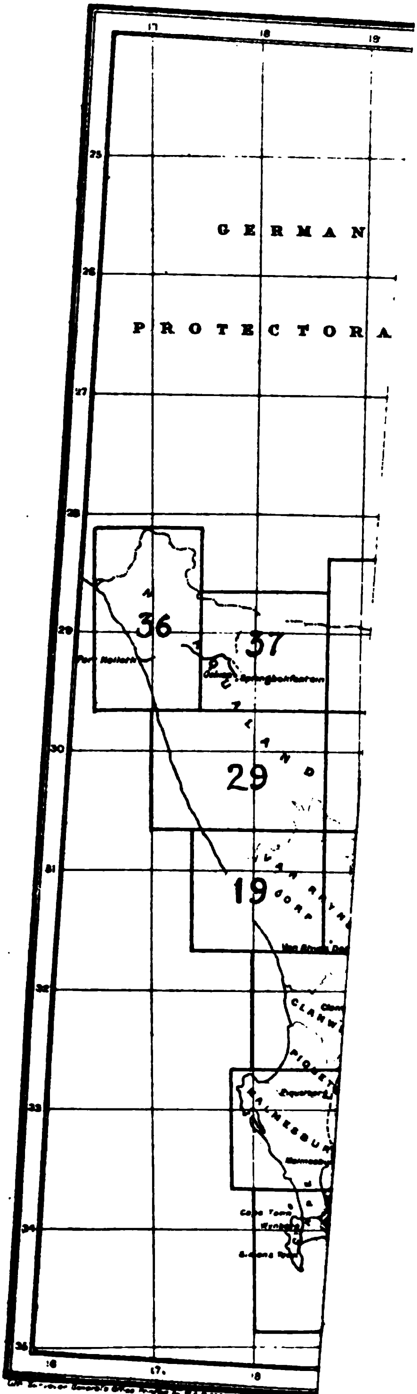
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P R O T E C T O R A
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Port Nolloth
Cape Town
Wynberg
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greater part of the Colony, but sheets 47–52 and perhaps 43 and 44 may be published on a smaller scale, 1 inch to 2,000 Cape roods (4.69 miles) or 1:297,500. The field work in that region is done on this scale, and it is useless to reproduce the results in a manner which can only magnify errors.

Various circumstances have made it undesirable to carry on the survey regularly from the south-western corner of the Colony towards the north and east, and the sheets of the coloured map will be issued without adherence to a regular order. The attached map shows the system of numbering adopted for the different sheets.

It is desirable that maps of this kind should be accompanied by a descriptive text, as is the case with the maps issued by several foreign surveys. In our case, however, this cannot be done at the present time; the preparation of the text would take more time than can be spared from the field work, and the cost has to be considered. The maps, moreover, cover ground which has been more or less fully described in the Annual Reports issued since 1896, and in future an attempt will be made to keep the issue of maps up to date as regards the areas described in successive Annual Reports.

The Palæontological work based on the Survey collections is progressing. Mr. Henry Woods' memoir on the Pondoland Cretaceous fossils is printed, and is now being issued.

The following papers written by the staff were published in 1906:—

"The Stormberg Formation in Cape Colony," by A. L. du Toit, British Association Report (Cape Town meeting), 1906.

"The Campbell Rand and Griqua Town series in Hay," by A. W. Rogers, Trans. Geol. Society of S.A., 1906.

"Underground Water in South-eastern Bechuanaland," by A. L. du Toit, Trans. S.A. Phil. Society, 1906.

ARTHUR W. ROGERS.

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GEOLOGICAL COMMISSION.

General Abstract of Receipts and Disbursements for the Year ending 30th June, 1906.

		£	s.	d.
To Balance 1st July, 1905		100	5	1
,, Government Grant		2,000	0	0
,, Sale of Horse		20	0	0
,, Municipal Fees—				
East London ...	£30 14 3			
Cape Town ...	6 6 0			
		43	0	3
,, Advances (current) repaid by Vouchers ...		260	0	0
		£2,483	5	4

	£	s.	d.	£	s.	d.
By Salaries	1,000	0	0			
,, Allowances, Personal	293	1	6			
,, do. Horse	26	12	0			
,, do. Cycle	9	14	0			
,, Railway Fares and Carriage ...	82	15	9			
,, Cart, Hire	8	9	6			
,, Postages	6	17	10			
,, Printing	66	6	2			
,, Books and Magazines	55	16	7			
,, Grazing for Oxen	7	0	0			
,, Analyses...	5	14	0			
,, Description of Specimens	20	0	0			
,, Rock Sections	9	12	9			
,, Horse Purchase Loss	39	15	0			
,, Oxen and Wagon	196	0	0			
,, Town Council Fees paid to Staff ...	43	0	3			
,, Shipping Charges	2	0	6			
,, Furniture and Equipment	86	6	8			
,, Boys' Wages	44	11	2			
,, do. Food	19	12	2			
,, Miscellaneous	4	3	3			
				2,027	9	1
,, Advances made				260	0	0
,, Balance as per Cash Book				195	16	3
				£2,483	5	4

THEODORE MACKENZIE, Secretary.

I certify that the above Account has been examined under my directions and is correct, and that the balance agrees with that shown in the Bank Pass Book.

WALTER E. GURNEY,
Controller and Auditor-General.

Control and Audit Office, 14th January, 1907.

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GEOLOGICAL SURVEY

OF

PARTS OF BECHUANALAND AND GRIQUALAND WEST.

BY

A. W. ROGERS.

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GEOLOGICAL SURVEY

OF

PARTS OF BECHUANALAND AND GRIQUALAND WEST.

BY A. W. ROGERS.

I. INTRODUCTION.

The country described in the following pages lies between the escarpment of the Kaap Plateau and the Langebergen, and includes a small area lying north of the Plateau.

The rocks on or near the surface in this district belong almost entirely to the Ventersdorp, Transvaal, and Matsap formations lying upon a floor of granite and schists (Kraaipan series), but this floor is only exposed at the extreme northern end of the area. There are no inliers of the basement rock. The covering of later rocks was folded in pre-Dwyka times into arches and troughs; the most important line of folds is that which forms the Langebergen, a wide arc of low mountains rising at the most some 2,000 feet above the country flanking them and concave to the west. All the other folds lie more or less parallel to this curved range, but the rocks involved in them are less closely folded. The chief of these eastern folds is that which gives rise to the Kuruman-Asbestos range, the eastern limb of a wide trough. Faults of sufficient importance to shift the outcrops considerably are very few; one of them, the Paling fault will be described below, another which passes through Takwanen is briefly mentioned, and a third traverses the base of the Transvaal system near Takoon. The two latter have not yet been fully traced.

East of the Kuruman range lies the Kaap Plateau, a region of very gently inclined strata. The earth movements which produced the western ranges scarcely affected the eastern part of the district.

Though in times long past this area must have been characterised by much greater contrasts between mountains and low ground, it is to-day a country of moderate relief; the plains are now more extensive than the hilly country. This general levelling is the result of two distinct periods of denudation, the first is of pre-Karroo and Dwyka age, and the second belongs to post-Karroo times. At present the country is being levelled up owing to the fact that the agencies of transport

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are not equal to the task of removing from the district a large part of the rock debris formed within it, so that the valleys generally are being filled up. This state of affairs is responsible for the fact that surface deposits of more or less recent age form an important section of the rock groups dealt with here.

The formations that appear at the surface are:—

Recent and Superficial Deposits.—Sand, gravel, surface limestones, quartzites, and ironstone.

(Great Unconformity.)

Dwyka Series.—Glacial boulder beds, shales.

(Great Unconformity.)

Matsap Series.—Upper; quartzites and sandstones.
Middle; quartzites, lavas, volcanic breccias and tuffs, and conglomerates.
Lower; quartzites, slates, and conglomerates.

(Unconformity).

Transvaal System

Griqua Town Series:—
Upper; jaspers, limestones, and phyllites.
Middle, or Ongeluk group; volcanic rocks and jaspers.
Lower; jaspers, cherts, sandstones, quartzites, glacial boulder beds, and thin limestones.

Campbell Rand Series:—
Limestones and dolomitic limestones, cherts, sandstones, quartzites, and a band of lavas in the north-east.

Black Reef Series:—
Quartzites, conglomerates, arkose, shales and thin limestones.

(Slight Unconformity.)

Ventersdorp System.

Pniel Series:—
Lavas and breccias of intermediate composition, thin flagstones.

(Unconformity).

Zoetlief Series:—Acid lavas.

(Great Unconformity.)

Kraaipan Series:—
Magnetite-schist and slates.

(Great unconformity?)

Granite and gneiss.

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Intrusive rocks of various kinds, but not acid varieties, occur in these rock groups, except the Recent and Dwyka.

Little work of a purely geological kind had been done in this area previously to this survey. G. W. Stow's paper[1] and a recent one by G. G. Holmes[2] are the only papers of importance, though brief references to the rocks are to be found in several books of travel, especially those by Lichtenstein, Burchell, Backhouse, Livingstone, and Fritsch, as well as in Penning's "Gold and Diamonds," 1901.

II. The Granite and Gneiss.

These rocks appear to be the oldest seen in the district. They only occur on the northern edge of it from Keang Kop eastwards as far as Hartebeest Laagte and England. This area was the northern limit of my work, and but few observations were made on the granite; the rocks have not yet been studied in thin section.

The character of the upper surface of the granite will be described in connection with the overlying formation, the Black Reef series, between Keang Kop and Takoon. From Takoon eastwards as far as England the amygdaloid and compact diabase lavas of the Ventersdorp group crop out near the granite, though the junction has not been seen. A bore hole on Hassforth, after passing through the diabase lavas, entered the granite without the intervention of other rocks. On Hartebeest Laagte, quartz-porphyries crop out between the granite and the diabase lavas on England, but no section through the junction was seen.

On the Motiton Reserve (which includes Takoon) the granite crops out in large masses near its southern boundary, and it is well exposed in the bed of the Mashowing River. The bulk of the rock is a pink biotite gneiss, and the strike of the foliation planes is between 10° and 25° east of north, but there are many large groups of outcrops of pink granite in which no foliation is observable. These massive granites have occasional porphyritic crystals of orthoclase in them, and are traversed by bands of grey biotite-gneiss and by veins of pegmatite, which generally lie parallel to the gneiss bands, but at places cut through them in various directions.

East of Takoon the granite crops out south of the diabase hill on which the Trigonometrical beacon stands, but north of that hill the outcrops become scarce. From this place to Hartebeest Laagte almost all the granite occurrences were noted from wells alone. On Zout Pan, however, there are outcrops in the pan which gives the place its name. The rocks are very similar to those on the Mashowing and at

[1] Quart. Journ. Geol. Soc., London, Vol. XXX., p. 581.
[2] Trans. Geol. Soc., S.A., Vol. VII., p. 130, 1905.

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Motiton, grey gneiss, pink gneiss, and massive granite, and pegmatites. The foliation planes are directed from N. 10° E. to N. 35° E. These outcrops project a foot or so above the flat floor of the pan, and the rocks are not deeply weathered; fresh specimens can be broken off without difficulty. The ground rises some 100 feet within half a mile of the edge of the pan, and on this slope there are shallow wells which go through the superficial deposits into the granite, and the granite is seen to be weathered to a distance of ten feet from its surface, the deepest exposed section at the time of my visit. These exposures all lie several feet above the floor of the pan.

III. The Kraaipan Formation.

There is a low, red, sand-covered ridge on the farms Hamburg and Kameel Rand; it lies nearly east and west, and it is continued west of Kameel Rand, though that part of its course has not yet been examined. On the two farms mentioned, there are two outcrops of magnetic schists and quartzites on the top of the ridge; on Kameel Rand three prospecting holes have been dug, and from these, together with the neighbouring outcrops, the following section was drawn:—

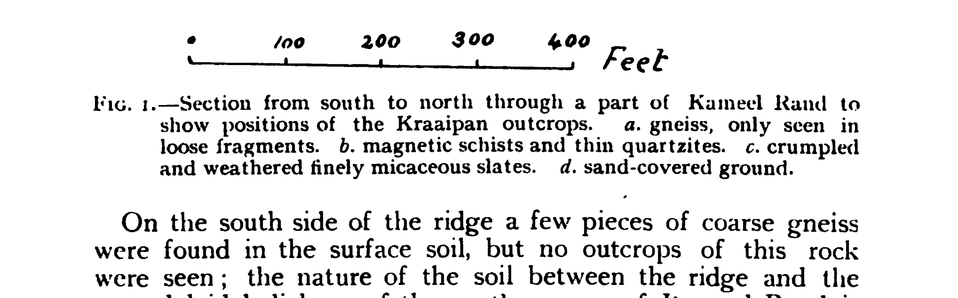

Fig. 1.—Section from south to north through a part of Kameel Rand to show positions of the Kraaipan outcrops. *a*. gneiss, only seen in loose fragments. *b*. magnetic schists and thin quartzites. *c*. crumpled and weathered finely micaceous slates. *d*. sand-covered ground.

On the south side of the ridge a few pieces of coarse gneiss were found in the surface soil, but no outcrops of this rock were seen; the nature of the soil between the ridge and the amygdaloidal diabase of the southern part of Kameel Rand is similar to that covering the granite and gneiss in the Mashowing Valley; quartz and dull felspar grains are abundant, and there can be no doubt that gneiss lies immediately south of the magnetic schist or other rock belonging to the same series. The contact is not exposed, and is not likely to be seen at any point along this ridge unless an artificial exposure happens to cross it.

The lowest beds of the Kraaipan series which I saw are rather coarse quartzites containing much magnetite, which is cleaved in such a way as to impart a distinct schistosity to the rock The magnetite is more abundant in some layers than in others, and the planes of schistosity are parallel to these layers in the specimens examined. The magnetic quartzites first dip northwards, but the strike varies between E. 30° S. and E. 10° N. in the small area over which they are exposed. The section seen in one of the prospecting trenches reveals many small dislocations which are too small to be shown on the section in Fig. 1. The quartzites are not closely folded as are the greenish-brown slates exposed in a cutting just to the north of them. Those slates are deeply weathered, but were evidently fine grained micaceous slate before they were altered by the weather. They lie in a syncline, for to the north of them appear the same magnetic quartzites that crop out to the south, but with a southerly dip.

Both the quartzites and slates are traversed by small quartz veins which were the object of the prospecting operations. Up to the present time, as far as I am aware, no quartz veins of considerable size or constancy have been found in this ridge.

The magnetic quartzites and schists of Kameel Rand are so like some of the rocks in the Kraaipan series described by Mr. du Toit in the Annual Report for 1905, that there is little room for doubt that they belong to the same group. At the end of my journey I went to Kraaipan and examined some of the sections and outcrops of the Kraaipan series. The magnetic rocks of the ridge near the station are of quite the same nature as those at Kameel Rand, and they only differ from the latter in being finer in texture generally, though coarse grained rocks are present. The exposures near Kraaipan, however, are on a much larger scale than those at Kameel Rand, and the junction with the gneiss is seen there. The mica-schists at the base of the Kraaipan series in the railway cutting near the station are not represented by any visible rocks at Kameel Rand, though the decomposed micaceous slates lying above the magnetite schist at the latter locality are not unlike some of the basal schists at Kraaipan. The Kraaipan section, as described by Mr. du Toit, shows no evidence of the intrusive character of the granite.

At a short distance north-eastwards from the cuttings on Kameel Rand, there is a pan in which several outcrops of the amygdaloidal diabase appear. These outcrops certainly belong to the lavas of the Ventersdorp series, and they were traced north-eastwards across Hamburg. They must overlie the Kraaipan formation in this neighbourhood, though a section showing the relation was not found.

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IV. The Ventersdorp System.

Under this term will be included two distinct volcanic groups, a lower acid series of lavas and an upper more basic series. This arrangement was adopted in the 1905 Report by Mr. du Toit as a result of his survey of the area lying just to the east of that which is being described here. Until the committee appointed by the British Association to consider and fix upon a uniform nomenclature for the larger South African rock groups has made its report, the term Ventersdorp system can be used without further discussion; and, as to the propriety of including the two sub-groups in that series, it is evident that convenience recommends such a course unless the break between the two sub-groups proves to be too great. There is certainly a considerable unconformity below the upper or Pniel beds, and the lower more acid lavas, the Zoetlief beds, but at present there is insufficient reason to make two large groups or systems, where one will include all the volcanic rocks lying below the Black Reef quartzites and resting upon a surface of gneiss, granite, or steeply-inclined sedimentary rocks of the Kraaipan or other older formation.

The possible relationship of the group of acid lavas in Vryburg to the Beer Vley volcanic series cannot be decided upon yet. Beyond the fact that the lavas of both these groups are more acid in composition than the amygdaloidal diabases of the Pniel series, there is no close resemblance between them.

A. The Zoetlief Series.

These beds in the area north-west of Vryburg, described by Mr. du Toit in last year's report, consist of arkose and quartzites at the base, more or less acid types of lavas, and a second group of sedimentary rocks at the top. A small area occupied by this series is included in the district under consideration. The acid lavas were first seen on Hartebeest Pan, where they crop out on sandy, rising ground at a considerable distance from the nearest granite or gneiss exposures to the west. The arkose and quartzite below the lavas are not exposed. On Kaffir Pan there is a considerable variety of acid porphyritic rocks, but they only crop out in small patches in the pan and near it, and no distinct bedding planes or divisions between flows were detected. In a small quarry on the same farm there is one nearly horizontal parting between a lighter-coloured porphyry above and a darker red porphyry below. In the immediate neighbourhood of this quarry a small cutting has been made, and a band of cherty quartzite eight inches thick exposed; the sedimentary rock probably lies above the pink porphyry in the quarry, and other outcrops of porphyry are seen above the level of the quartzite.

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The lavas vary considerably in the amount of quartz present as porphyritic crystals or corroded crystals, and in the relative proportions of the felspar and quartz crystals; the colour also varies, the most usual matrix is a light red felsite, but almost white, pale green, and blue felsitic rocks were seen on Kaffir Pan, Harbro, Klip Fontein, and Schildpad Kuil. Ferro-magnesian constituents are not visible to the naked eye, and thin sections of the rocks are not yet available.

From England to Manchester the nearest outcrops south of the porphyries are bluish amygdaloids belonging to the Pniel series. The junction between them is not exposed, but the fact that the position of the lowest blue amygdaloids seen on Schildpad Kuil varies in level by 100 feet or more within a short distance, points to the surface of the acid lavas being rather uneven. The want of clearly-exposed divisional planes in the acid lavas near Schildpad Kuil prevents a comparison of their dips with those of the overlying Pniel lavas being made in this neighbourhood.

B. The Pniel Series.

The group of amygdaloidal lavas and other rocks lying below the Black Reef series, to which Stow gave the name of Pniel beds, has now been followed from the Vryburg area down the valleys of the Dry Harts and Vaal to the Orange River, and there is no question as to the various outcrops of amygdaloidal diabases below the bulk of the Black Reef series belonging to one group of rocks.

There is, however, some doubt as to the propriety of drawing a strong divisional line, as between two rock systems, between these lavas and associated rocks and the Black Reef series in the Vryburg area. The sections described below from Motiton and Takoon are sufficient to show that in this area the lavas and the Black Reef series are very intimately connected; and the interbedding of similar lavas with the sedimentary rocks of the Black Reef and Campbell Rand groups near Vryburg, as described in last year's report,[1] and again, from the country further west in this year's report, decidedly support this view.

The great unconformity between the diabase lavas and the overlying Black Reef series in the Transvaal,[2] as shown by differences in dip in sections where both formations are exposed, does not appear to exist in the Vryburg area. The overlapping of the Black Reef series west of Vryburg is probably due to the original thinning out of the lower group westwards, and to the irregularity of the surface on which the lavas came to rest, rather than to the denudation of the volcanic rocks before the Black Reef beds were laid down.

[1] Du Toit, Ann. Rep. Geol. Comm. for 1905, p. 247.

[2] Molengraaff, Geology of the Transvaal, 1904, pp. 21 and 29.
Hatch and Corstorphine, Geology of South Africa, 1905, p. 153.

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Proceeding eastwards from the western side of the Motiton Native Reserve, the first outcrop of amygdaloidal diabase, which lies between the granite and the Black Reef beds, is seen about a mile and a half east of the church at Motiton; it is partly covered by a northward projecting tongue of Black Reef beds, and a small outcrop of similar lava is seen on the eastern side of the same tongue nearly two miles further east. The junction with the overlying beds is not well exposed.

An isolated outlier of the lavas forms a hill in the fork of the Mashowing River, just west of the chief village at Takoon, but the Black Reef beds do not cap the outlier, which consists of amygdaloidal and compact diabase.

On the ridge south of the store at Takoon the amygdaloid reappears, and was followed uninterruptedly eastwards to the neighbourhood of Massouw's Kop, where Mr. du Toit's work ended in 1905.

As will be more fully described below, the base of the Black Reef series near Motiton is formed by arkose, and at Takoon a precisely similar arkose lies below the diabase lavas.

On the ridge, about half a mile south of the store at Takoon, very interesting sections are exposed. The ground on either side of the ridge is made of granite and gneiss, which also crop out at the west end of the ridge, above the right bank of the main head-stream of the Mashowing River; the ridge itself is a tongue of diabase, partly lava and partly intrusive work, projecting westwards from the main body of those rocks east of Takoon. Near the west end of the ridge, and on its north side, arkose is seen to lie below the lowest lavas, and thin beds of arkose are intercalated with lava higher up the slope of the hill. Large masses of arkose, quite irregular in shape, are enclosed in the lower and highly vesicular lava flows. On the south side of the ridge the junction is complicated by the intrusion of compact blue diabase, which sends thin veins downward along the joint planes in the granite. There is a great contrast in general appearance between the slaggy lava of the north side and the intrusive rock on the south side of this ridge, but the distinction is not easy to follow through the main body of lavas in the upper part of the ridge. On examination of the Black Reef escarpment south-east of this ridge, where a considerable area of amygdaloidal lava intervenes between the granite and the Black Reef beds, the latter were found to consist entirely of quartzites, conglomerates, and felspathic quartzites; no rock containing enough felspar fragments to be called an arkose was seen there. At the place where that tributary of the Mashowing which rises on the farm Pretoria Uplands leaves the Black Reef beds, there is a section showing white glassy quartzites belonging to the latter, resting on compact blue diabase, which cuts

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across the bedding planes of the quartzite. The junction of the diabase with the granite is not visible, though only a few feet of silt-covered ground separated their outcrops in the river bed at the time of my visit. The white quartzite seen in this section is obviously part of the Black Reef escarpment, and it has a strongly marked vertical prismatic jointing near its contact with the diabase. There is here clear evidence that the diabase is intrusive, and that the peculiar glassy and brittle character of the quartzite at this spot is due to its influence. The amygdaloidal lavas are not seen in this section, and there is only room for a small thickness of arkose, if it exists here.

The interest of these sections showing the intrusive nature of the compact diabase lies in the evidence they give of the intrusive character of rock which, in less well-exposed outcrops, would have been mapped in as an integral part of the volcanic series. The intrusive rock, as seen in a hand specimen, is so like the amygdaloidal lavas that the presence of the amygdales alone distinguishes them, yet the absence of amygdales would not be sufficient evidence to decide the intrusive nature of diabase seen in more or less isolated outcrops in the volcanic group. In the country near the hill on which the geodetic beacon Takoon stands, there is a large body of compact diabase, but there is at present no clear evidence of its character. The separation of the intrusive rock from the lavas in the greater part of the area occupied by the Pniel group cannot be carried out now.

The diabase ridge on which Takoon beacon stands is partly separated from the main outcrop by a tongue of granite and gneiss exposed in the valley of a tributary of the Mashowing from Bosch Plaat and Kopjes Laagte. On the farm Bethlehem greenish-blue flagstones are quarried from about the middle of the series; the flags are used for building and fencing poles. The amygdaloidal lava is exposed at several places on the strip of country, from four to five miles wide, made of this series between Takoon and Kameel Rand, though the ground is usually covered with reddish sand, which in some prospecting pits on Hassforth are seen to attain a thickness of from 20 to 30 feet. At Kameel Rand the width of the volcanic belt decreases by one-half, and at the same time the surface slopes more steeply upwards from the probable position under the soil of the southernmost granite to the foot of the Black Reef escarpment. From Hamburg to England the volcanic belt widens, and reaches a width of ten miles. In this wide tract the rocks are not often seen; considerable areas of very flat ground, covered with grass and hard soil, mark its position. On Schildpad Kuil and between the Schildpad Kuil hills and the geodetic beacon V.c. on Bok Kraal, the volcanic beds make a low escarpment, capped for the most part by the Black Reef beds.

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A section seen on the north-western slope of a hill on Schildpad Kuil is recorded here:—

Grey-green breccia forming the summit of the hill	40 feet.
Compact blue diabase	20 „
Blue amygdaloidal diabase	50 „
Grey amygdaloidal lava, more acid rock than the blue amygdaloid	4 „
Blue amygdaloid, with occasional very large amygdales	30 „

The bottom group of lavas in the above list is thicker than 30 feet; it forms the base of the hill and stretches northwards about half a mile from the hill; beyond that distance the quartz-porphyries of the Zoetlief beds crop out.

The fine-grained green flaggy beds lie above the green breccia of Schildpad Kuil; they are first seen some distance south-east of the hill, and they are overlain by a further thickness of amygdaloidal lavas. The beacon V.c. on Bok Kraal is on an outlier of the Black Reef, about 400 yards from the main outcrop of that group, and the lavas on which it rests contain chalcedony amygdales up to 12 inches in length.

The diabase lavas and associated breccias and fine-grained blue flagstones have a low dip towards the Black Reef beds in their vicinity. The angle of dip is difficult to measure with accuracy, but it never seems to exceed 5°.

The thickness of the group increases eastwards; at Motiton, as we have seen, it does not exist west of the Church and Police Camp. At Takoon beacon it is about 200 feet, rather less than over that amount. At Hassforth a borehole has been put down on the Black Reef beds, through the volcanic group to the granite; the record of the core was not available, but the owner of the farm, Mr. Hassforther, told me that about 400 feet of core like those fragments of it which I identified as belonging to the Pniel series were brought up, so the total thickness at this place probably does not exceed 400 feet. On Schildpad Kuil the whole thickness is between 300 and 400 feet. At Vryburg there are at least more than 500 feet of rock belonging to this formation.[1]

In a well on Hamburg some 40 feet of blue sedimentary rock are exposed in the Pniel series, but no conglomerates were met with. Throughout the area of Pniel beds west of Vryburg, there were no conglomerates or quartzites seen. The only coarse fragmental rocks are breccias, evidently of volcanic origin, and the blue flaggy beds.

[1] Ann. Rep. Geol. Comm. for]1905, p. 241.

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Neither the sedimentary nor the igneous rocks of the Pniel group in this area have yet been examined under the microscope.

The lava outcrops throughout this area are fresh; only a very thin crust of weathered rock conceals the fresh material. Where the rock is only seen in wells or other excavations in sand-covered ground, it is always more deeply weathered. On Hassforth, where from 20—30 feet of sand overlies them, the lavas are decomposed to a depth of quite ten feet below the bottom of the sand. A similar phenomenon is noticeable in the granites of the Mashowing valley. It is doubtless due to the effect of the ground water kept in contact with the diabase for long periods by the sandy covering.

V. The Transvaal System.

That the rocks older than the Karroo formation in Griqualand West included representatives of strata developed in the Transvaal has been known for many years. In Mr. Dunn's map of 1887 a large group of beds common to the two countries is called the Lydenburg group, but its limits were not defined; this term was revived in 1904 by Dr. Passarge[1] to include the beds between the bottom of the Black Reef and the top of the Pretoria beds; in the same year Dr. Molengraaff, after abandoning the correlation with the Cape formation, used the name Transvaal system[2] for this group, and that name is now generally used. The first geologist to trace the connection between the two countries in the field, and thus to establish definitely the correlation of the Campbell Rand series with the dolomites, and of the Griqua Town series with the Pretoria beds, was Mr. G. G. Holmes.[3]

The Transvaal system in the Cape Colony will here be held to include the beds from the base of the quartzite and conglomerate above the Pniel lavas, or resting directly on still older rocks when the latter are wanting, and the top of the Griqua Town series. As a result of the past year's work, the Griqua Town series has been enlarged to include the Ongeluk volcanic beds and sedimentary rocks lying with apparent conformity on them.

A. The Black Reef Series.

This group of rocks was traced through a distance of 55 miles from the eastern of the two beacons called Keang Kop (Keang Kop A) through Motiton, Takoon, Hassforth, and Geluk to New York, where the outcrop joins the area mapped

1 Die Kalahari, 1904, p. 49.
2 The Geology of the Transvaal, 1904, p. 24.
3 Trans. Geol. Soc., S.A., Vol. VII., 1904, p. 130–132, and a map.

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by Mr. du Toit in 1905. The nature and distribution of the beds in this area are given by Mr. Holmes in the paper referred to above, but some further details are here added.

The Black Reef series gives rise to an escarpment which stands out prominently east of Motiton, but becomes less conspicuous, though still the most important feature in the relief of the ground east and north-east of the Motiton Reserve, as far as Utrecht. North-east of Utrecht the escarpment is continued by the lavas of the Pniel series, rocks which also make a prominent ridge for a short distance near Takoon Kop.

The series consists of quartzites, grits, felspathic quartzites, conglomerates, arkose, shales, flaggy argillaceous quartzites, and calcareous grits. If the limit between it and the overlying Campbell Rand series be taken at the top of the highest quartzites, then the Black Reef series includes some thin beds of dolomitic limestone. Near the road leading south from Motiton to Kgatlogomo there is a section showing thin limestones, interbedded with brown-weathering quartzite, and lying below some 10 feet of similar quartzite; there are beds of calcareous grits below these limestones. The choice of a divisional line is a matter of little practical importance at present, but for the purposes of my mapping, I drew it at the top of the highest brown quartzites on the Motiton-Kgatlogomo road. It is rarely that one finds sufficient outcrops to decide the exact position of the boundary wherever the choice may lie; though by far the greater part of the distance through which the boundary was traced it might lie anywhere within 100 to 300 yards. If drawn at the top of the highest quartzites, there is more likely to be consistency in line throughout the map than if the lowest dolomite or limestone band be chosen as the limit. It is frequently the case that the neighbourhood of the boundary is marked by a slight depression, and at Mooi Fontein the large brak-water pan is in that position.

Between Keang Kop A and Motiton, and at places between Motiton and Takoon, the base of the formation lying on the granite is well exposed. In each place examined there are some feet of arkose lying directly on the granite. The arkose is over 30 feet thick over Motiton, and the change in composition through felspathic grits and quartzites to more or less pure quartzites is gradual in each section. At some spots it is difficult to find the precise limit between the granite and arkose; the granite is deeply weathered, and so also is the arkose. Pebbles of granite are not often seen in the arkose, but pebbles of vein quartz are so abundant in some layers that the rock is a conglomerate with an arkose matrix.

The arkose was not found where the Black Reef beds rest upon the Pniel series, nor was a rock corresponding to arkose, but made of diabase debris, seen in those localities. I did not find pebbles of diabase in the Black Reef conglomerates, though

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chalcedony, which may have come from amygdaloidal diabase, is rather abundant, in the form of rounded pebbles. Mr. du Toit found water-worn pieces of diabase in the Vryburg conglomerates. The contrast between the contents of the basal beds on the granite and those on the diabase is very marked, however, and it occurred to me, when taken into consideration with the above-described sections at Takoon (p. 16), to indicate a rapid succession in time of the basal Black Reef beds to the underlying volcanic rocks in this area.

The junction with the Pniel series is not so frequently or so well exposed as that with the granite, but at the beacon V.c. on Bok Kraal, and on the southern part of Schildpad Kuil, the junction is seen, and the lowest beds of the Black Reef series, slightly felspathic quartzites, rest upon amygdaloid and breccia respectively at the two places.

The felspathic quartzites are a characteristic feature in the Black Reef beds, though quartzites without a sufficient quantity of felspar to be noticed by the unaided eye are equally widely distributed. The felspathic quartzites seemed to be most abundant in the western part of the area examined.

The conglomerates in this series were seen at Motiton and Takoon, where prospecting has been carried on, at Hassforth, between Geluk and Doorn Poort, Mooi Fontein, and New York. They are not regularly distributed throughout the area on one or more horizons, but are probably in lenticular layers rarely a foot thick. In four traverses between Hamburg and New York, only two outcrops of a conglomeratic rock were seen; but the rocks are not well exposed. The pebbles are of quartz, chert and chalcedony, granite, and dark slatey rock, but granite is not abundant. The matrix is quartzite, with pyrites or rusty iron ore sparsely disseminated through it. Coarse grits were seen at Motiton, Takoon, Hassforth, and Geluk; they always contain felspar fragments. The thick-bedded rocks in this series are usually strongly false-bedded. The flaggy beds are thin ripple-marked quartzites. Hard grey or blue argillaceous flagstones are occasionally interbedded with the more usual quartzites. The thin blue limestone or dolomite interbedded with the uppermost quartzites near Motiton is just like the similar rock of the Campbell Rand group, and the calcareous grit is a limestone containing a considerable proportion of quartz grains.

The dip of the Black Reef beds is southwards at angles usually less than 5° along the northern edge of the Kaap Plateau. Between Tampans Fontein and Vryburg there is a low synclinal fold, and the dips become more easterly on the west side of the syncline.

The middle of this synclinal area is traversed by a fault, with downthrow on the east side; there is an inlier of the Black Reef and volcanic rocks connected with the fault on Goedver-

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wacht, Lochnagar, and the Takwanen Reserve. The structure of this inlier on Takwanen has not yet been worked out; there is a difficulty in separating the Pniel volcanic rocks from those close above the Black Reef quartzites, in the absence of numerous outcrops. This inlier will be more fully examined next season. Though the structure of the inlier is at present doubtful, there can be no question that the conglomerates exposed at several places along the western side of the "aar" north of Lochnagar belong to the Black Reef series. They have a low westerly dip under the dolomite west of the fault. The fault coincides with the "aar," which is also the position of a dolerite dyke.

B. The Campbell Rand Series.

This formation occupies almost the whole of the Kaap Plateau, and a large tract of rather similar country lying to the west of the syncline of the Asbestos Mountains, between the neighbourhood of Postmasburg and the Kathu Forest; the latter area may be called the Maremane anticline, from the large Native Reserve which lies entirely within it.

(a) The Kaap Plateau.

The Kaap Plateau is a roughly triangular area, with its base stretching from Vryburg westwards to Tsenin, on the Kuruman River, and its apex near the Orange River, at Read's Drift, an area of over 6,000 square miles. The Plateau appears to be remarkably flat to a person travelling across it in any direction, and the shallow dry valleys on its surface have so slight a slope that it is sometimes difficult to decide the direction of fall when walking in them. There are but few hills on the plateau, and these usually have gentle slopes, and do not rise more than 100 feet above the surface in their neighbourhood. Towards the western side there are a few abrupt hills in the area where chert is more abundant than in other parts of the Plateau; those hills are made of chert and limestone, *e.g.*, the hills on Pakhane, Kono or Koning, Kogel Been, and between that farm and Daniel's Kuil. North of Daniel's Kuil there are hills made by outlying masses of the Griqua Town beds; one of those is the hill called Ramaje's Kop by Stow.[1]

The highest point on the Plateau is probably the hill on which the beacon Khaw stands, 5,032 ft.,[2] and the valley of the Kuruman River below the Magistracy is probably under 3,900 feet; the edge of the Plateau between Vryburg and Campbell lies at about 4,000 feet, or slightly above that level. The difference in level, therefore, at various parts of the surface is over 1,000 feet, but they are brought about so gradually that the Plateau appears to be flatter than it really is.

1 G. W. Stow, Q.J.G.S., Vol. XXX., p. 665.
2 Report of the Surveyor-General for 1901, p. 9.

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The inlier of the Black Reef series and volcanic rocks near Takwanen is of considerable size, quite ten miles long from north to south, yet it makes no feature on the surface, though the great contrast in character between the rocks exposed in it and the dolomitic limestone which entirely surrounds it leads one to expect a hill or belt of rising ground marking the position of the inlier.

The eastern limit of the Plateau is the escarpment trending a little west of north from Vryburg to the Griqualand West boundary near Taungs, and thence in a more south-westerly direction to the Orange River, near Read's Drift. The edge of the Plateau does not coincide with the base of the Campbell Rand series, which is found in the valley (Dry Harts, Harts, and Vaal) below, usually buried for considerable distances under the Dwyka series or recent deposits.

The surface of the Plateau is well covered with grass and bush, but over very wide areas it is extremely uneven, owing to the presence of projecting angular lumps of chert and dolomitic limestone. These rocks project a foot, or even two feet, above the soil. In other areas surface limestone appears above the soil every few feet. Generally speaking, the soil is thin; only in some of the shallow valleys and in the sandy country does the soil become thick. The pans, which are extremely numerous on the Plateau, have rock floors in most cases; in others, however, the floor is made of soft white tufaceous limestone. Towards the western side of the Plateau, especially north of Griqua Town, the Plateau becomes more sandy, and in the Kuruman area there are wide stretches of country in which there are no outcrops either of the Campbell Rand series or of surface limestones; in these tracts the limestones are met with in wells a few feet below the sand.

The surface of the Plateau usually falls slightly towards the western boundary, which is formed by the Kuruman-Asbestos range, made by the escarpment of the Griqua Town series.

With the exception of the inlier of older rocks mentioned above, the Plateau is made almost entirely of the Campbell Rand series, dolomitic limestones, cherts, and shales. The long, low, and narrow ridges called "aars," usually found to consist of white tufaceous limestone, are not infrequently seen. In many cases they are certainly due to the presence of dykes of dolerite or other igneous rock traversing the Campbell Rand series. These aars will be described more fully in that section of the report which deals with the intrusive rocks.

The Campbell Rand series in the Kaap Plateau consists mainly of dolomitic limestones with which chert is often associated. Shales occur at many places, especially towards the bottom of the series. On Mount Carmel, a farm about 15 miles north of Daniel's Kuil, there are bands of shale interbedded, with thin limestones and cherts within 40 feet of the top of the

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series. These shales were searched for fossils without success, as was also the case with the shales well exposed near the base of the series at Baviaans Krantz, and near Geluk in Vryburg.

The dolomitic limestones and cherts were briefly described in the last Annual Report,[1] and there is not much new information to add about these rocks generally A peculiar rock is sometimes met with, interbedded with the dolomitic limestones. It is an obviously oolitic rock. Thin sections cut from this oolite from an outcrop on A. 23, in the north of Hay, show that it is almost entirely composed of quartz [1606, 1606A]. The outlines of the oolite grains are not visible under the microscope. The whole is made up of small interlocking grains of quartz, the size of which varies considerably; a few grains are large enough to show the uniaxial character of the mineral. Examined in ordinary light, the sections show some brown colouring matter arranged round straight-edged areas, which are evidently sections of rhombs; in polarized light between crossed Nicols the rhombs are scarcely visible, because the areas enclosed by the straight edges are parts of adjacent quartz grains, whose boundaries do not coincide with the stained edges. The quartz within these areas is more cloudy than that outside them, owing to the inclusion of very minute black specks; in many cases there are also very small black needles, which appear quite opaque, even in the thinnest examples. These needles do not occur outside the sections of the rhombs. Both in these areas and without, the quartz encloses very minute crystals and grains of a very highly doubly refracting and colourless mineral, certainly a carbonate.

This is, without doubt, a silicified oolite, which was formerly made of carbonates. Professor R. B. Young has described such rocks from Griqualand West, together with analyses, and he pointed out that they become indistinguishable from some quartzites.[2]

The cherts are more abundant in the upper half of the series than the lower, though in some places where the passage from the Campbell Rand beds up into the Griqua Town series could be followed closely, as at Gamohaan or Kuruman Kop, and on the hillside north-west of Daniel's Kuil, chert does not occur within about 100 feet of the top of the former group. Where chert is very abundant, *e.g.*, between Daniel's Kuil and Nelson's Fontein, it often occurs in large mases which have a convex upper surface, though the dip of the overlying dolomitic limestone does not conform to this surface, but steadily maintains its uniform low angle wherever the inclination can be observed.

1 Ann. Rep. for 1905, pp. 152–154

2 The Calcareous Rocks of Griqualand West. Trans. Geol. Soc. S.A., vol. x., 1906, p. 57.

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These convex masses have irregular flattish hollows within, lined with quartz. They appear to lie on one and the same horizon, as Stow states in his description of them,[2] for they were seen again on the Kono Reserve, south of Kuruman, at approximately the same vertical distance from the top of the series.

Between Moroping and Kuruman village there are large masses of black chert exposed on the veld. One of these measured from 6 to 10 feet across, and made a dyke-like outcrop, traced for over 100 yards. In another case the chert formed a lump, irregularly rounded in outline, 30 feet in diameter, and projecting 6 feet from the ground.

Though much of the chert occurs in such irregular forms, which cannot have been taken at the time when the limestone was being deposited, there are bands which maintain a uniform thickness and appearance over considerable areas. One bed of finely-banded chert was traced for over 400 yards round a slight rise on Mount Carmel, and throughout that distance it is 5 inches thick.

The sections on the slopes of Gamohaan (the native name of the hill often called Kuruman Kop; on the Divisional map the name is applied to the high point on the escarpment behind on which the geodetic beacon stands) are of considerable interest. The hill is capped by an outlier of Griqua Town beds, nearly 100 feet thick. The passage from one formation to the other is undisturbed by the process of solution and collapse noted in several localities and described below. The uppermost limestones are rather thin-bedded, and are coloured with green and pink tints, thus looking different from the usual blue or grey limestone of the bulk of the series. These variously-coloured beds contain numerous spherical lumps of rusty iron ore and haematite, up to half an inch in diameter. Two layers of similar limestone were seen above the lowest beds of banded magnetic jaspers in the outlier. The grey limestone about 150 feet below the top of the series, near Gamohaan, has a peculiar spheroidal structure, only visible on weathered surfaces; it is due to the presence of concentrically-arranged layers of rock, about one-twentieth of an inch thick, of slightly different composition, which weather at different rates, and have not quite the same colour (shades of brown), due to the accumulation of iron oxides. The spheroidal shape of these structures is evident on the angular weathered blocks. In no case could I detect with a lens any such structure on a freshly-broken surface. Another peculiar structure gives rise to columns and arches on vertical sections of layers up to two inches thick, and traceable for several yards. The appearance reminded me of the Cotham limestone in the English Lias, though the columns are more regularly placed in the Gamohaan rock.

[2] Stow, *loc. cit.*, pp. 658, 659.

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The spheroidal lumps of iron ores were observed in unusually coloured limestones on Mount Carmel, and again, during the previous year, on the Enkelde Wilgeboom inlier on the Orange River. In both these cases their position is within a few feet of the top of the series.

Water in the Kaap Plateau.

The dolomitic limestones of the Kaap are traversed by many narrow passages, along which water may still flow. The remarkable spring at Kuruman, which yielded, according to a measurement made by me in September 1906,[1] $5\frac{1}{4}$ million gallons a day, issues from the base of a low krantz of limestone, but it receives additions from springs which rise from the sandy

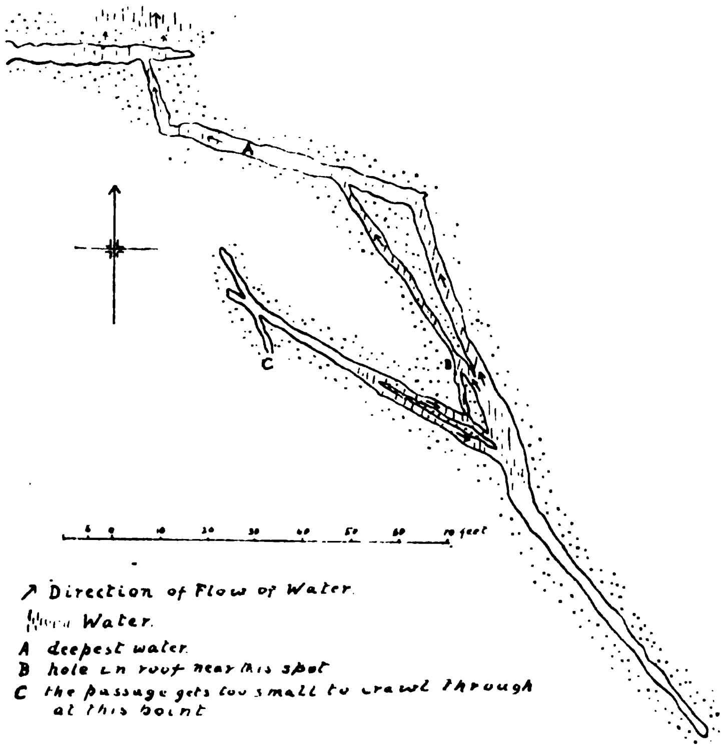

FIG. 2. Plan of Kuruman Cave.

bottom of the pool below the krantz. There is a hole on the west side of the mass of limestone forming the krantz, down which one can drop into a passage behind the krantz. A plan of the passages (Fig. 2) was made by means of a compass and

[1] The measurement was made by timing floats over 68 feet of a recently-cleaned part of the furrow on erf No. 17, some 700 yards below the drift at Kuruman.

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tape, and the annexed diagram is a copy of it.[1] A considerable part of the passages is dry at the present time, and, judging from the amount of earthy matter lying on the dry floor, some considerable time may have elapsed since water flowed over these parts. Neither the floor nor the roof maintains the same level for any considerable distance. At the point marked A, the floor is lower than elsewhere, for the water is four feet deep there; from this point the floor rises in each direction. The roof is not far from the surface of the ground; at a spot near B daylight is visible through it. In other places the roots of bushes hang down from the roof, or have entered the passages through joints in the limestone. The plan of the cave shows clearly enough that the passages are merely widened joints. The width of the passages varies considerably, and at most is about 8 feet. Though the walls, which have an inclination towards the south of west, are in many places coated with a deposit of carbonate of lime, there are few well-developed stalactites; those which were once there have been broken off.

There are said to be other caves or passages in the Kaap Plateau, on the Kono Reserve and Kogel Fontein. The strong springs which issue from the level ground on the Manyeding and Groot Vlak Fontein Reserves, and on Bothetieletsa, may well come from similar fissures in the limestone. Near Geluk there is a well-like hole through shaly limestones, in which water stands at a level of about 17 feet from the surface. The supply was maintained when 270,000 gallons a day[2] were being pumped out.

Springs are more numerous and yield a larger volume of water in the Plateau than in any other part of the area between the escarpment and the Langeberg range. In several places I was assured that these springs do not yield as much as they did a few years ago, and on several farms the springs marked on the Divisional map were not flowing in 1906. With regard to the Kuruman spring, there is no evidence to decide whether the flow is less than in former years. The people in Kuruman say that the flow is constant throughout the year, and from year to year also. There is, however, a dry channel, not long deserted, at a slightly higher level than the present exit of the main spring, and unless the water which once flowed along the higher channel has found a lower exit, the flow must have decreased.

The Kuruman spring issues at a spot which lies at a comparatively low level, and its position is such that it would be possible for the water which falls on a very large part of the Kaap Plateau to find exit there. The geological structure of the country is also such that the limestone strata, so favourable to

[1] I was kindly assisted in making the plan by Mr. J. H. E. Mayne, Magistrate's Clerk at Kuruman.

[2] This figure was taken from an engineer's report shown me by Mr. Abt.

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the development of underground channels of considerable width, dip gently towards the Kuruman hills from the east; therefore, if there were any obstacles, such as impervious beds, faults, dykes, or vertical masses of chert, which impede the flow of water westwards under the Kuruman hills, it would issue on the east side of those hills. My survey failed to discover any such impervious body of rock or dislocation likely to intersect the westward flow of the water from the Plateau, and so I cannot assign a reason for the occurrence of the spring at the particular spot where it issues. There can be little doubt, however, that the water at Kuruman and the other smaller springs on the Plateau comes eventually from rainfall on the Plateau. All these waters are very hard; their temperature is above the air temperature on a cold day and below it in hot weather; at Kuruman, the water was at 64° F. at the drift in July and November.

There is no such strong spring as the Kuruman fountain at any other place on the east flank of the Kuruman-Asbestos range, though small springs are not infrequent. Near Daniel's Kuil there are dykes of dolerite traversing the dolomite approximately parallel to the strike of that rock. These dykes (possibly the isolated outcrops belong to one and the same dyke) are probably responsible for the appearance of the fairly strong supply of water at the surface at Daniel's Kuil village. In this part of the Plateau the drainage lines run eastwards, towards the escarpment on the Vaal River valley, and the conditions are therefore less favourable to the occurrence of a large quantity of water than at Kuruman. The springs and wells near Daniel's Kuil were plainly showing in 1906 the effects of deficiency in rainfall during the past ten years.

The hole in the ground from which Daniel's Kuil got its name may originally have been similar in nature to the water-hole (called the Wondergat) at Geluk; but the Daniel's Kuil is dry, and there is no record of its ever having had water in it. Both holes certainly owe their existence to the removal of rock by solution. In the case of Daniel's Kuil, the limestone is no longer visible in the hole, which is now about 15 feet deep, and in process of being filled up with rubbish; the walls are made of a reddish earthy material, and they recede some feet from the opening, which is through a hard ferruginous gravel.

(b) *The Maremane Anticline.*

This area of the Campbell Rand series occurs along the crest of a broad anticline, which has been traced from the south of Hay in a north-north-easterly direction to the neighbourhood of Klipfontein (north of Postmasburg), and thence in a north-north-westerly direction to Kathu. The dolomitic limestones first appear at the surface between Wolhaars Kop and Sweet

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Fontein, on the Postmasburg River, and they are constantly seen as far north as the dry valley which traverses the anticline from the Khosis Reserve to Gamagara. North of this valley the Campbell Rand beds were not seen, but there can be no doubt that they underlie the country between Kathu beacon hill and the north end of the Gamagara ridge, for the calcareous tufa or surface limestone becomes very thick in that area, and the dip of the Griqua Town beds on the Kathu beacon hill is directed away from this tufa-covered ground.

In general appearance this dolomitic limestone area resembles the Kaap Plateau[1]; the character of the vegetation is the same and large parts of the surface are very rough in detail, though, disregarding the hills of Blink Klip breccia, the whole looks flat. The ridges and outliers of Blink Klip breccia are, however, very characteristic of this anticline, whereas a precisely similar rock does not occur in the Kaap.

On the east the Campbell Rand limestones dip at low angles under the Griqua Town beds of the ridge which extends south-eastwards from Kathu beacon to the neighbourhood of Riet Fontein, in Barkly West, and thence south-westwards past Postmasburg. This boundary shows very distinctly the rather extraordinary bend which all the main structural lines take in southern Bechuanaland and the north of Griqualand West.

The southern extremity of the limestone disappears under surface deposits east of Wolhaars Kop, but its approximate position is not difficult to lay down on the map, because there are outcrops of the younger beds in suitable places. From Wolhaars Kop northwards to M. 93, the limestone dips at low angles under the Griqua Town beds, which there form a low ridge. An outlier of the latter beds, or an extension of a band of them lying south of the Vlak Fontein syncline,[2] partly separates the limestone of the western border from that of the main area, but the surface deposits conceal the details of the structure between this patch of Griqua Town beds (on M. 80 and M. 93) and the south end of the Gamagara ridge. The dolomitic limestone crops out west of that ridge, between it and the Ongeluk beds of the Vlak Fontein syncline; but there must be faults here, in addition to the Paling fault, the existence of which is greatly confirmed by the results of last year's work. The position and nature of the subsidiary faults must remain uncertain for the present, owing to the general thick covering of surface deposits and the lack of artificial exposures. From the south end of the farm Paling to the westernmost corner of Sekgame, in the Kuruman district, a distance of about 34 miles, the limestone

[1] The name Kaap Plateau seems now to be confined to the country east of the Kuruman—Asbestos range, but on some of the original diagrams of farms in the Hay portion of the Maremane anticline, *e.g.*, Klipfontein, the farm is said to lie on the Kaap Plateau or range.

[2] See Ann. Rep. Geol. Comm. for 1905, p. 188.

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area is bounded by the Blink Klip breccia of the Gamagara ridge. The condition north of Kathu will probably remain unknown for a long time, for the country there is covered with a thick deposit of tufa, and the two dry valleys leading northwards to the Kuruman River through this neighbourhood are not excavated deeply enough to expose their bed rock, or, more probably, they have been filled in with tufa too deeply to allow the rock to appear below Cowley in one case and Gamagara in the other. The Paling fault probably extends some distance north of Sishen. The downthrow is to the east, though at an earlier stage it must have been to the west.

In character the Campbell Rand beds in this area are very like those in the Kaap Plateau, and there is no need for a special description of them. The upper beds are not so well exposed here as on the Gamohaan and Daniel's Kuil hills. As a whole, this area is less well watered than the Kaap; there are considerable springs at Postmasburg, which issue near the outcrop of a dolerite dyke, though this dyke appears to terminate some hundred yards from the springs. Further down the Postmasburg River (dry), there are also strong springs rising from the calcareous tufa, which, to a great extent, hides the underlying rock in that neighbourhood. The wells on the Maremane anticline are not numerous, and there have been several failures amongst the few sunk. The depth to which they have been sunk is not great, not more than about 60 feet. Boring for water has not been attempted, so far as I know. There can be little doubt that water will be got by boring, though, as the area has a smaller catchment than the Kaap, and as the beds are in the form of an anticline, the quantity available is almost certainly less than in the latter district. I have left out of account the possibility of some of the water from the Kaap flowing under the wide syncline of the Kuruman hills, etc., for the level of the surface west of the syncline is only slightly lower than that of the Kaap, and its rocks form an arch which is separated from the possible source of supply, not only by the syncline but also by a large area of the Ongeluk volcanic rocks. The structure under this volcanic area is not known, but it is not improbable that there are dykes or other bodies of igneous rock which may interfere seriously with the movements of water underground.

At the present time the limestone areas have a bad reputation for stock farming, but when the farmer can properly guard against "lamziekte," the great possibilities in the way of underground water supply in these areas will attract people. Boring operations will not be easily carried out, for the difference in

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hardness between the dolomitic limestone and the chert, which will almost certainly be met with in the greater number of holes, will make difficulties, as will also the hollow spaces dissolved out of the limestone by the underground water.

Volcanic Rocks in the Campbell Rand Group.

In the 1905 Report, p. 247, Mr. du Toit describes some lavas at the top of the Black Reef beds near Vryburg. Similar lavas were found on New York, lying above the Black Reef beds, and separated from them by several feet of thin dolomites and dark shales. This band of volcanic rocks was not seen on Mooi Fontein or Geluk, nor further west. Its thickness is probably under 100 feet. The rocks are very like the lavas below the Black Reef.

Though they lie on a somewhat higher horizon, judging from the lithological character of the sedimentary rocks, these lavas are almost certainly a continuation of the belt mapped last year.

C. The Griqua Town Series.

The past year's work has made it advisable to extend the meaning of this term so as to include both the Ongeluk volcanic group and certain sedimentary rocks overlying these in the north-west of Hay and the south-west of Bechuanaland.

In the Report for 1905 it was stated that the sedimentary rocks west of the Lucas Dam syncline belong to the upper part of the Griqua Town series, but I was then under the impression, owing to a strong lithological resemblance between the two sets of rocks, that these western beds were merely a repetition of the beds seen east of the supposed syncline, and that there was an overfold here. An examination of the northward continuation of the same belt of country has shown that the views expressed in that Report are wrong, and a re-examination was made of part of the belt seen previously in Hay. This has shown that the view now adopted is very probably correct, and the new view clears up several difficulties that were not met by the old. The error was corrected too late to be made good in the text of the 1905 Report, but a fly-sheet, dated October 15th, 1906, was printed for distribution with the Report, and the error is pointed out therein.

The reasons for thus enlarging the Griqua Town group will be apparent from the facts described below.

The Griqua Town series occupies a wide area in this district. It first occurs in the long line of hills called the Asbestos and Kuruman ranges, the eastern limb of a wide syncline in this group. The western limb gives rise to the lower range stretching from Kathu, past Khosis, to near Postmasburg, where it is

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..ent round towards Wolhaars Kop, or concealed by recent deposits for some miles; it or a similar structure can, however, be followed in isolated patches of rock past Matsap into the eastern limb of the anticline between the Juanana and Abram's Dam synclines. West of the line of country indicated, the structure is more varied, owing to the presence of several synclines in the south. The formation disappears under the Matsap beds of the Langeberg group of ranges in such a way that the fullest succession is seen in the north, and the gap represented by the unconformity at the base of the Matsap series becomes steadily greater towards the south.

It will be convenient to describe the rocks and their distribution under three heads:—

3. Upper group, sedimentary rocks.
2. Middle or Ongeluk group, chiefly volcanic rocks.
1. Lower group, sedimentary rocks.

(1.) *Lower Group.*

This group includes all the rocks above the Campbell Rand limestones and below the lowest volcanic rocks of the Ongeluk group. Thus defined, it builds up the Asbestos-Kuruman range, the Kathu-Khosis hills, the hills south of the Matsap area and between the latter and the Langebergen, the Wolhaars Kop ridge, and the peculiar breccia hills of the Maremane anticline.

The rocks of this group were described in the last Annual Report,[1] so there is no need to repeat the description here, but a few fresh specimens of the more abundant types of rocks have been examined under the microscope, and more examples of the glacial beds have been similarly dealt with.

A banded black, brown, and white magnetic rock from Jacob's Fontein, in Hay (1589), is seen under the microscope to contain a large amount of colourless or slightly yellow-stained cherty material, made of very small quartz individuals, which overlap each other and are intricately interlocked. Through this run lines along which iron ores are concentrated. These lines are the lamination planes of the rock seen in section. The iron is in two forms, magnetite and an opaque brown ore. The magnetite is mostly in thin layers and irregularly-shaped clusters of grains, but it also occurs in certain rhomboidal areas which are seen in the section. These areas range up to one-fiftieth of an inch in length, and are scattered sparsely through the chert matrix, being often only distinguishable by a narrow limiting line of brown oxide of iron; the material within this limit is often chert, just like the chert outside, but there are sometimes irregular patches of brown iron ore with or without minute grains

[1] Ann. Rep. Geol. Comm. for 1905, pp. 156–164.

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of magnetite in them. Along the lamination planes those rhomboidal sections are much more abundant than elsewhere, and in these planes they are generally filled in, chiefly with brown oxide, together with some magnetite. In a few cases the magnetite almost fills the area to the exclusion of both the brown oxide and the chert. The rhomboidal sections represent former crystals of carbonates, and the hydrated and magnetic oxides of iron in these sections are secondary products. It is likely that carbonate of iron (siderite) was once a constituent of the rock, and that at least part of the iron ores now forming a considerable portion of the rock are due to an alteration of the iron compounds originally in the deposited sediments. A difficult question to settle is whether all the brown oxide now present is a direct result of changes in the carbonate of iron supposed to have existed formerly, or whether some or all of it is due to the oxidation and hydration of the magnetite.

A fine-grained sandstone, brownish and grey in colour, from a depth of about 40 feet in a well on Westfield, shows in thin section (1601) a collection of quartz grains, evidently of detrital origin, cemented together by a matrix of a pale greenish-blue chloritic mineral and perhaps chert. There are also numerous small patches of a carbonate with brown oxide of iron. There is nothing referable to crocidolite in this section.

A section (1595) through a heavy banded blue, green, and brown rock from Kort Kloof Fontein is seen under the microscope to have a base of chert crowded with needles and matted tufts of two minerals, one of which is yellow and shows fairly high colours between crossed nicols, and the other is pale greenish-blue with low double refraction. The needle-like crystals are mostly of the blue mineral, and the denser parts of the aggregates are formed chiefly of the yellow, but the two minerals are certainly closely related, probably one of them is an alteration product of the other, and it is more likely that the blue is the earlier. This greenish-blue mineral resembles that called chloritic in the previous paragraph, and is not the same as the pleochroic crocidolite seen in some of the Griqua Town rocks of Prieska[1] and Hay.

A section (1492) has been made of one of the very tough, heavy blue rocks, fragments of which are frequently picked up on the surface in Prieska and Griqualand West. It consists almost entirely of densely-matted fibres of crocidolite, but there are scattered through the crocidolite small paler areas, in which there appears to be some chert.

The Glacial Beds.

During the past year these beds have been examined at places where they have undergone much less change than at the locali-

[1] Ann. Rep. Geol. Comm. for 1905, p. 157.

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ties described in the 1905 Report. The specimens described below from thin sections come from the south-eastern side of the large syncline of Ongeluk beds in the middle of Hay, and from the outliers on Good Hope, in Barkly West. The chief difference which separates these rocks from the glacial beds in some other localities is that they are dark blue-grey in colour, and the fragments of limestone in them are preserved. The prevailing red and brown colours of the glacial beds over a great part of their extent were remarked upon in the 1905 Report, and it was also stated that certain cavities partly filled with iron ores possibly represent original limestone pebbles. Limestone pebbles are abundant in the blue rock from the localities mentioned above; the limestone is a finely crystalline white marble, occasionally it is banded owing to the alternation of thin grey and white laminae.

A section (1593) through the blue rock from Kort Kloof Fontein in Hay shows that a large part of the matrix is carbonate of lime or magnesia in small irregular crystalline grains; a rough estimate of the amount of carbonate present in the section gives its proportion as one-third of the whole. With the carbonate there is a colourless very fine-grained chert; in this matrix lie small angular and rounded grains of clear quartz, minute ragged flakes of a slightly pleochroic pale-brown mineral which seems to be bleached biotite, a very few grains which may be felspar, crystals of magnetite, and a grain or two of a highly refracting and polarizing mineral, such as zircon, which, however, was not determined with certainty. Chert and marble form larger fragments. In some cases the pieces of chert are sharply bounded, and appear to have been much in their present condition since the rock was deposited, but in most cases the chert pebbles are so impregnated with carbonates that they almost lose their distinction from the matrix, and give rise to the impression that they represent a stage in the change of limestone pebbles into chert. One of the limestone pebbles has circular areas in it partly converted into chert along concentric layers; these are probably oolitic grains. There are also oval areas of chert in this pebble; there is nothing that can be assigned without much doubt to radiolarian or other organic remains.

Sections (1581, 1582) from the glacial rock on Good Hope, in the Barkly West Division, show a fine-grained matrix, consisting of very small grains of carbonates of lime and magnesia, very small quartz grains, and much indeterminable dusty matter; no chert is discernible. Small sections of octahedral crystals of magnetite are fairly abundant. In this matrix are set larger grains of quartz, angular or rounded, and similarly shaped grains of felspar (orthoclase and microperthite, not microcline or striped plagioclase) which are not abundant, chert, marble, and a few flakes of biotite—fresh, not altered as in the Kort Kloof rock. The chert grains and small pebbles are very sharply defined,

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and are made up either entirely of chert or have some carbonates and magnetite in them. There is one rounded pebble of pyrites. One grain of a grit rock is to be seen, but no fragment of an igneous rock, other than the felspar, mica, and quartz grains, is visible.

These three slices are probably typical of a large body of the glacial beds. The rock breaks with a splintery fracture. On Good Hope it has been used for building a house, and though the stone was quarried within the last six years, it is already flaking off on exposed surfaces, and in places it is breaking down into a sandy material.

The difference in position and circumstances between the places where the blue rock, covered only by a thin crust of yellow-brown weathered material, occurs, and those where the red and brown rock described in the 1905 Report are found, will not account for the changes which have taken place in the latter rock. The absence of quarries and wells from the red rock, also, prevents a knowledge of any changes which may be found at shallow depths from the surface. From the generally-observed fact that where the red rock is, the other beds of the Griqua Town series are also highly haematitic, and that corresponding beds in the blue rock areas are not so haematitic, it is obvious that similar changes affect large bodies of rock, and there is as yet no explanation of the circumstances governing the change.

The Blink Klip Breccia.

Though this rock in its typical form appears to be confined to the Maremane anticlinal area, it has been pointed out that the minor disturbances of the basal beds of the Griqua Town series are closely related to the processes that gave rise to the breccia itself.[1] So the account of the work done last year on the breccias will be commenced by a description of the disturbed beds at the base of the Griqua Town series, along the Kuruman-Asbestos range.

On the east side of the Blockhouse Hill, just north of Daniel's Kuil, there is a good section showing, in the lower half of the slope, the dolomitic limestone of the Campbell Rand series inclined at a low angle westwards; then comes a layer of thinly-banded jasper, which is highly disturbed, and this is followed by about 10 feet of limestone, which is also folded in conformity with the underlying jasper. Above this limestone lie thin-bedded jaspers, disturbed below, but gradually becoming flatter and flatter above. About half a mile north of the blockhouse, where the hill is higher, and consequently is capped by a greater

[1] Trans. Geol. Soc. S.A. Vol. IX, 1906.
Ann. Rep. Geol. Com. for 1905, p. 166, 178-9.

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thickness of Griqua Town beds than further south, the thinly-banded jaspers are very little disturbed. In another section, a few hundred yards north of the one described above, the main body of jaspers descends obliquely across the upper 10-foot limestone the thin jasper band and part of the lower and main group of limestones. These descending beds are folded into a sharp synclinal form, and there is broken rock visible below them in a few spots where exposures occur in suitable positions; the broken rock probably represents the thin bed of jasper. The total displacement of the upper jaspers reaches a maximum of quite 30 feet.

Similar sections are visible below the hill on which the Gamohaan beacon stands, north-west of Kuruman.

There are probably many places between Kuruman and Griqua Town where sections more or less similar to those at Daniel's Kuil can be seen, but for long stretches the junction is concealed by soil, angular debris, and ironstone gravel.

On the farm called Mount Carmel, and on A. 112 and A. 113, there are seven outliers of the Griqua Town beds lying at various distances up to $1\frac{1}{2}$ miles eastwards from the main body of the series. One of these outliers was identified without difficulty with the hill called Ramaje's Kop by Stow,[1] and through which he drew a section. I could not find any spot where the

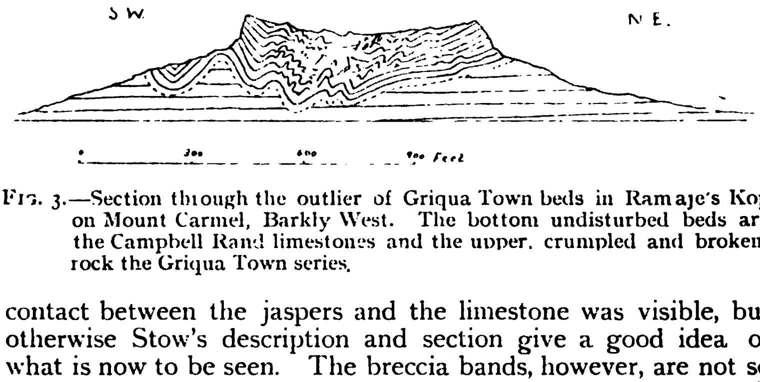

FIG. 3.—Section through the outlier of Griqua Town beds in Ramaje's Kop on Mount Carmel, Barkly West. The bottom undisturbed beds are the Campbell Rand limestones and the upper, crumpled and broken, rock the Griqua Town series.

contact between the jaspers and the limestone was visible, but otherwise Stow's description and section give a good idea of what is now to be seen. The breccia bands, however, are not so definite as Stow's drawing would lead one to expect. A generalised section through this hill is represented on Fig. 3. The details are too intricate to be inserted, but the main points are the existence of the folds on the western side of the hill and of the highly broken zone in the middle, followed by much less disturbed beds on the north-east side; the Campbell Rand limestone is well exposed round the lower half of the hill, and shows no deviation from the steady westerly dip. The trend of the largest fold in the jaspers is about W.N.W., but in the central part of the outlier there is no recognisable order in the positions

[1] Q. J. G. S. Vol. XXX, p. 665.

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of the various blocks and fragments of these rocks. In this place the Griqua Town beds seem to have collapsed into a cavity, of which the W.N.W. axis was rather longer than any other; the cavity must have been deep enough to bring about the fracture of the jaspers in the part where they had to move furthest, *i.e.*, the middle of the hole.

On the beacon hill at the south end of Mount Carmel there are intensely folded beds. The axial planes of these folds may lie in any direction, some of them are nearly horizontal. The length of a limb between trough and arch may be as much as 5 feet. The junction of these contorted Griqua Town beds with the limestone is not seen, but, as usual, the latter rock lies undisturbed in the lower slopes of the hill. The folded rock is very well exposed here, and the sharply curved surfaces of many beds can be examined closely. They show no slickensides, such as are seen, *e.g.*, on the surfaces of the folded Witteberg beds north of the Zwartebergen. They give one the impression that the folding took place when the jaspers were in a plastic condition, so that layers moving at different rates did not scratch one another. These facts appear contradictory of the evidence afforded by the brecciated parts of the rock, for the latter is made up of quite sharp-angled fragments of the banded jaspers. The phenomena in these hills, in fact, seem to show that the process of adjustment of the Griqua Town beds to the hollows dissolved out of the limestone is to be divided into two parts: (1) an earlier adjustment when the beds dropped down by their own weight and at a time when they were plastic, and (2) a later filling in of the enlarged holes by the falling down of the fractured hard beds.

Though the outliers north of Daniels Kuil contain rock which is indistinguishable from some of the Blink Klip breccia, the latter only occurs in its typical forms in the Maremane anticline.

In the 1905 Report[1] a description was given of those masses of the rock within the Hay Division, but a further examination has been made of two important localities in Hay, the kopje near Postmasburg and Wolhaars Kop, which could only be cursorily looked at in the former year.

The breccia which forms the hill near Postmasburg (the Blink Klip Kop or Sensavan) makes an oval outcrop about 500 yards long in a N.N.E. direction and 300 yards wide. On all sides the Campbell Rand limestone appears at the surface, and the actual contact of the two rocks is to be seen at several spots round the northern end of the hill. On the north-eastern slope there is a large cavern, from which the natives have dug out red haematite from an unknown date. The walls of the cave are made of breccia containing a very large proportion of haematite, and between masses of the usual hard rock there are bodies

[1] Ann. Rep. Geol. Com. for 1905, pp. 174–179. Figs. 3 and 4 in that Report (pp. 172 and 176) were unfortunately transposed.

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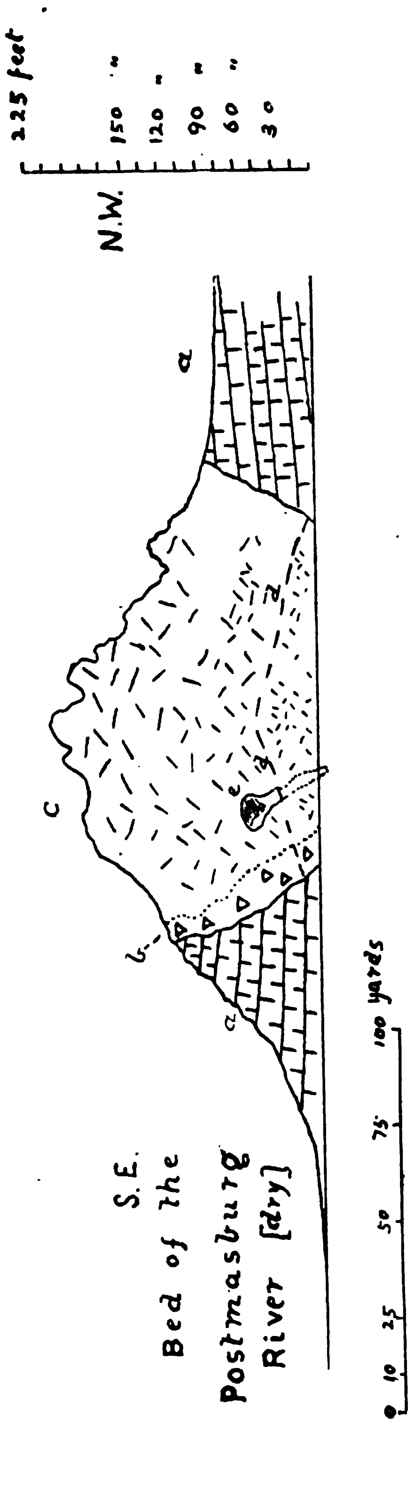

FIG. 4.—Section through the Blink Klip Kop. *a.* Campbell Rand limestone. *b.* brecciated limestone. *c.* Blink Klip breccia. *d.* dotted line showing position of limestone breccia on N.E. side of hill. *e.* excavation made by natives.

of softer haematite, quite irregular in shape. This soft haematite can be crushed between the fingers, and was evidently the chief object of the natives' search, for the cave has been enlarged in all directions along streaks and pockets of this substance. There are variously shaped patches and strings of calcite in the breccia, otherwise no other material than the haematite breccia is to be seen in the walls of the cave. From the cave a narrow passage leads downwards in a southerly direction, which I followed for about 40 feet; the floor is soft haematite, and the walls and roof are a very irregularly-shaped surface of the hard rock. A farmer near by told me that he once went 50 yards down the passage, but that it has become blocked by fallen rock. This extension of the cave may perhaps be in part an original feature, though its present size is certainly due to excavation by the natives. The Campbell Rand limestone crops out on the eastern side of the hill at a height of about 80

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feet above the lowest part of the cave accessible at the time of my visit, and on the western side it is seen to be about 40 feet above the same level; directly north of the hill it crops out a few feet above the level of the cave floor within a distance of 50 yards. Fig. 4 shows a section through the hill drawn roughly to scale. Between the limestone on the east and the typical breccia there is a belt of brecciated limestone containing a small amount of haematite; this belt is nearly 10 feet wide, and extends round the north end of the hill. There are spots on the eastern flank of the hill, where a limestone breccia probably does not exist, for the normal limestone and the haematite breccia approach each other very closely.

In this hill, therefore, we have a proof that the Blink Klip breccia here fills a fissure or elongated hole in the Campbell Rand limestone, which is practically undisturbed a few feet from the breccia, and in places unbroken up to its contact with the latter. At no other locality has such complete evidence of the position of the breccia been obtained, though the partial section given on p. 172 of the 1905 Report indicated such a position.

The lower part of this hill consists of richly haematitic breccia in which the irregular fragments of banded jasper are less numerous than usual; the matrix is increased in quantity. Small crystals of iron pyrites were seen occasionally in the red haematite. On the southern slope of the hill there is a second excavation, now almost filled by the falling down of the roof or walls, and the rock exposed there is similar to that in the large cave. The top of the hill is made of the hard breccia described in the 1905 Report.

Wolhaars Kop is a prominent summit of a ridge 10 miles south-west of Postmasburg. It lies on the western side of the anticline, where the beds begin to have a decided westerly dip. The Campbell Rand limestone forms the low ground east of the kop, and the western slope is cut out of the usual banded jaspers of the Griqua Town series; then follow the Ongeluk volcanic rocks and the uppermost division of the Griqua Town series. Thus the whole succession from the Campbell Rand beds to the unconformity which truncates the Griqua Town series in Hay is seen in this neighbourhood. The breccia of the Kop lies between the limestones and the westward dipping banded jaspers. In last year's Report it was stated that the breccia is over 200 feet thick; but the maximum thickness must be nearly 400 feet, though it is difficult to draw a line to indicate the upper limit. Near the eastern base of the hill and for some 200 feet up the slope highly haematitic rocks containing angular fragments of banded jaspers and chert are seen. In the upper part of the hill occur banded rocks, very much broken up, and cemented together again by haematite and iron-stained silica; these rocks are great shattered masses, just like those described last year from the Klip Fontein ridge. The general trend of

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the shattered rock is about N. 10° E., roughly parallel to the western limit of the anticline in this neighbourhood. These broken-up banded rocks give place to less broken beds as one descends the western slope of the hill, *i.e.*, as one traverses higher and higher beds in the stratigraphical succession, and finally unbroken beds are met with. The banded cherts of the western slope are in places repeatedly faulted on a small scale; the throw of any one fault may be only an inch or less, or it may be several inches. Both normal and thrust faults are seen. A thick band of reddish quartzites interbedded with the cherts seems to have checked the fracturing of the rocks, for above it the beds are not broken.

The Klip Fontein ridge extends into the Kuruman Division, and is in all about 22 miles long. The Thaakwaneng Trigonometrical beacon (5,180 feet) stands on it. There is not much to add to the description of this ridge in the 1905 Report. On the east side of the ridge near Thaakwaneng the Campbell Rand limestone rises high above the base of the breccia. Northwards from this ridge there are several outliers of the breccia situated on the Maremane and Khosis or Gathlose Reserves. Though not quite aligned on the extension of the Klip Fontein ridge, seven of these outliers are nearly in that position. These hills are made of ferruginous and siliceous breccias very like those of the Klip Fontein ridge. Eight more of these outliers were found in the Maremane Reserve and to the south of it. The Bechuanaland rinderpest fence crosses two of these; the larger one is the Mount Huxley of the maps. Mount Huxley is a mass of breccia with its longer axis lying N.N.W. The limestone crops out at higher levels than the lowest visible breccia at both the north and south ends of the hill. The breccia is rather less ferruginous and more siliceous than the average rock of the Klip Fontein ridge.

The curiously abrupt crag called Kopje Aleyn lies about two miles N.N.E. from Mount Huxley. It is a mass of breccia with a rough vertical jointing, rising very steeply from the grassy flats on the farm Gopthorne.

The Gamagara ridge is the longest mass of the Blink Klip breccias; it is the extension of the Paling ridge in Hay, but as the well-known name of Gamagara is applied to the Trigonometrical beacon (4,105) standing on it, that name can be used for the whole ridge. The ridge stretches from Paling to Sekgame, a distance of some 31 miles, though it is probably discontinuous on Lomoteng, where the Campbell Rand limestones seem to be in direct contact with the Matsap beds for some few hundred yards. The material in this ridge is very like that in the Klip Fontein mass; much of it contains a large proportion of haematite. The rocks have not yet been analysed, and there is no need to repeat the description of the various kinds of breccia, which differ from each other in the amounts of iron ores and

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silica, and in the degree of comminution of the banded fragments. There are two special points of interest in this ridge. Firstly, the occurrence of crater-like hollows on Bruce; and secondly, the fact that the breccia is directly overlain by the Matsap beds. The southern crater-like hollow on Bruce is about 50 yards wide, filled in with red sand and surmounted by a rather steep wall, 10–15 feet high, of more or less broken, highly-ferruginous banded rocks; great slabs of this rock dip sharply towards the hollow on the south-east side. On the north-west side there is a break in the wall, caused by running water. The hollow at once reminded me of the Balmoral (Fraserburg) volcanic pipe, but there is no evidence, such as the occurrence of unusual minerals in the floor of the hollow, that the latter had the same origin as the Balmoral pipe. It seems likely that the hollow is situated on a circular sink-hole in the limestone, but there is no means of settling the question at present. The northern hollow on Bruce is similar to the one just described, but it is wider (about 120 yards wide), and its walls are lower.

The lowest part of the Matsap beds are very ferruginous when they lie on the breccia, and well-rolled fragments of the latter rock were found in the Matsap beds. In places the Matsap beds are so largely made up of debris of the breccia that the distinction between the two rocks is not easily drawn. The occurrence of layers of fragments and the bedding of the Matsap beds with constant westerly dip, however, separate them from the breccia. These rocks will be mentioned again on a later page.

In the Gamagara ridge there are slickensided surfaces in the breccia; their appearance is sufficient to show that they were subsequent in date to the formation of the breccia. Probably they represent small faults, produced at the same time as the long fault which forms the western boundary of the Gamagara ridge (see Fig. 5).

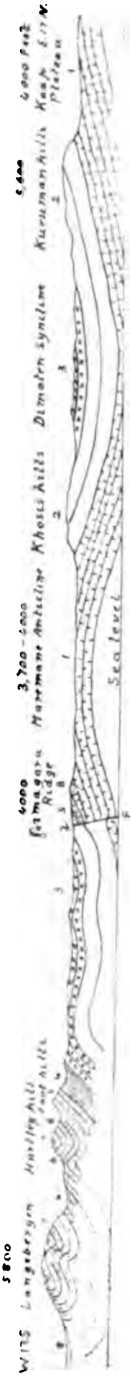

Fig. 5.—Section from the Kaap Plateau to the Langebergen, distance 66 miles; vertical to horizontal scales, 3 to 1. 1. Campbell Rand series. 2. Lower Griqua Town beds. 3. Middle Griqua Town beds, or Ongeluk beds. 4. Upper Griqua Town beds. 5. Lower Matsap beds. 6. Middle Matsap beds. 7. Upper Matsap beds. 8. Surface sand, etc. B. Blink Klip breccia. F. Paling Fault.

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From the occurrence of boulders and smaller debris of the breccia in the Matsap beds, the age of the breccia is determined, at least as regards its later limit; and it is clear that a great part if not all of the haematite had also been accumulated when the Matsap beds were deposited.

The Distribution of the Lower Griqua Town Beds.

The chief area where these beds crop out at the surface is that of the Kuruman-Asbestos range, which trends S.30°.E. from the Kuruman River[1] past Kuruman to the Barkly West boundary; then it turns southwards past Daniel's Kuil to the Hay boundary, and trends S.S.W. past Griqua Town to the Orange River. The great bend in the strike about the line running E.N.E. from Andries Fontein has been referred to before, and is very clearly seen in the case of this boundary. The beds in this area dip westwards under the Middle or Ongeluk group in Hay and Kuruman, but these volcanic rocks in the syncline have been entirely removed by denudation over a wide area west of Daniel's Kuil, and probably also between the Dimoten volcanic area and that of Langar, etc., west of Kuruman. The Lower Griqua Town beds reappear in the western limb of the syncline as the Kathu-Khosis hills, the Groen Water hills, and the low hills near Matsap (see Fig. 5). They then form the eastern limb of an anticline, which is wide in the north (Maremane anticline), but which contracts southwards, and can be recognised in the rather narrow anticline between the Juanana and Abrams Dam synclines described in the 1905 Report. The westernmost occurrences of these beds seen during 1906 are near the Matsap outliers in the Koegas Field-Cornetcy, in the narrow strip on the west of the Paling fault, and in the Wolhaars Kop hills.

The observed range of the glacial beds has been extended as far north as the country north of the Kuruman-Kathu road, on the farms Ettrick and Cropwell, where good specimens of striated stones were found lying in a fine-grained matrix. West of the Paling fault, the glacial beds were traced up to Bishop, and they are well exposed on Lomoteng. They are seen round the Dimoten syncline of Ongeluk beds, and the two outliers of the latter called Monjana Mabedi. These are prominent hills on the north-east side of Khosis Reserve; a corner beacon of that Reserve stands on one of the hills. The upper 200 feet or so of each hill consists of lavas, and the lower 150 feet of the Lower Griqua Town beds. The glacial beds are not very well exposed, but in a few gullies they are seen, and in these situations, especially near a dried-up spring on the south-eastern hill, the rock is decomposed into a muddy material, from which the

[1] For the northward continuation of this range see the paper by G. G. Holmes in Trans. Geol. Soc. S.A. vol. VII. p. 130 and plate.

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enclosed stones can be picked out. Where outcrops occur on other parts of the hillside, the rock is the hard blue variety, like that of Good Hope, with a thin weathered crust. At Monjana Mabedi there are some 12 feet of thin-bedded dark quartzitic rock lying between the highest outcrops of the glacial beds and the lowest Ongeluk lavas. Although the boulder beds are here calcareous and contain much limestone, in the shape of fragments of marble, the dark rock overlying them is not calcareous.

On the south-eastern part of the Ongeluk-Witwater syncline there are good sections exposed on the hillsides, showing a succession like that given in Fig. 6 of the beacon hill of Punt, Dunmore, and Schanz. The occurrence of the 40 feet of quartzite with pebbles (No. 4 in Fig.) is rather peculiar, for beds with

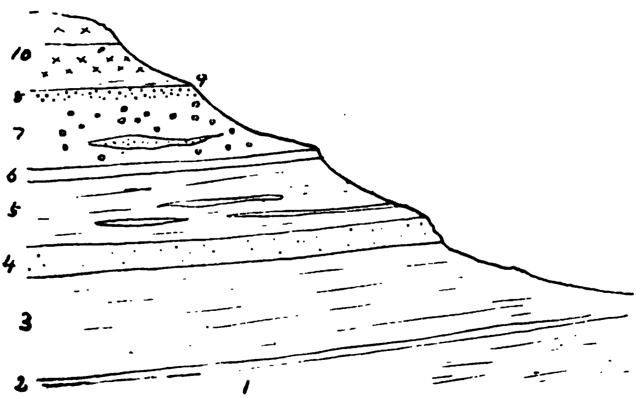

FIG. 6. Section on the hill where the beacon common to Punt, Dunmore and Schanz stands. 1. Brown magnetic jaspers. 2. Flaggy blue fine grained rocks. 3. Thin bedded ferruginous rocks; 100 feet. 4. Coarse quartzitic sandstone with pebble beds; 40 feet. 5. Thin bedded ferruginous rocks with lenticles of limestone. 6. Hard black jaspery rock. 7. Blue quartzitic mudstone with striated boulders, a patch of gravel in the mudstone. 8. Gravelly conglomerate; 8 feet. 9. Blue thin flaggy beds; 12 feet. 10. Ongeluk lavas.

similar characters are not often seen on this horizon, though their hardness would cause them to make good outcrops. The quartzite contains grains of felspar and pebbles of cherty ferruginous rock; some of them are now represented by lumps of ochre. On Koodoo's Kop a very felspathic sandstone occurs on about the same horizon, *i.e.*, some 200 feet below the lowest lavas, and is 30-40 feet thick. A grey quartzite in a similar position was noticed east of Matsap. In the Kuruman district no rock of this kind was seen in the Lower Griqua Town beds, though the exposures between Khosis and Monjana Mabedi are so complete that any rock of this nature would have been seen if present; near Monjana Mabedi there are grits just below the

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glacial beds, as there are in several places in Hay, but these grits have nothing to do with the thick sandstones and quartzites at the lower horizon in Hay.

(2) *The Middle Griqua Town Beds.*

The Ongeluk volcanic beds form the greater part of this sub-group. The stratified sedimentary rocks other than volcanic debris associated with the lavas consist of banded jaspers. These rocks were partly described in the last Annual Report, p. 182, but other varieties have been found, and thin sections cut from a few of them. They are all brittle rocks, and all more or less banded, owing to the greater abundance of iron oxides or other colouring matter in some layers. It is rarely that they are well exposed *in situ*; they are usually seen as fragments along certain lines, the latter probably mark the positions of the strata under the soil. On Hartfell (Koegas F.C., Hay) there is an outcrop of bright red jasper between thick masses of lava in the Abrams Dam syncline. A section (1604) has been cut from this rock perpendicularly to the banding; it is seen under the microscope to be made up of small quartz areas, like chert, with red colouring matter through it. The colouring matter is in the form of extremely minute dots, without definite shape so far as one can see with a one-eighth inch objective; the small circular areas in which these dots are crowded have a reddish appearance in transmitted light. These crowded areas measure ·07 mm. or less in diameter, and in at least a great number of cases each crowded area lies within one individual grain of quartz (or other form of silica). Certain bands of the rock are fairly free from clusters of dots, and the quartz areas in them are somewhat larger than in the red part; these are the white layers of the hand-specimen. The banding is occasionally interrupted by the appearance of roughly circular or oval clear patches, rather irregular in outlines, and made of rather larger quartz areas than the bulk of the rock. Magnetite occurs in small octahedra. There are several flakes of a peculiar green mica, a mineral similar to the mica in one of the banded magnetic rocks of Doornberg[1] (on the farm Nauga). The absorption scheme is that of ordinary biotite, except that shades of green take the place of the red-brown colours of biotite. A few small colourless garnets are cut through by the slice. In some hand-specimens of this jasper from other localities the garnets are one-tenth inch in diameter, and have pale yellow and brown colours. On Taaibosch Puts a banded black, green, and grey cherty rock occurs. The black portions are very magnetic. Under the microscope, the ground mass is chert, or quartz in much larger individuals than in chert. The black part is due to the occurrence of vast numbers of very minute grains of magnetite,

[1] Ann. Rep. Geol. Com. for 1905, p. 157.

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apparently without crystal forms. The green bands are chiefly epidote in rather large yellow pleochroic plates. The grey bands are mostly chert or quartz, and what seems to be garnet. The mineral taken to be garnet is in spherical aggregates without crystal faces; it is nearly colourless, and has a higher index of refraction than epidote, and it is isotropic. In most parts of the slice these aggregates are to be seen; often they coalesce over considerable areas to form irregular layers. The smaller aggregates are of such a size that they lie within the thickness of the slice (·02—·03 mm.), and the layer of chert outside them is still thick enough to give light-grey tints between crossed Nicols, so that these small lumps do not appear to be isotropic. That they are really so is shown by their behaviour under contiguous but differently orientated quartz individuals, when each portion extinguishes with the remainder of each quartz area.

The explanation of the peculiar constitution of these coloured cherts or jaspers has not been found. Their mode of occurrence points to their having been sediments laid down between successive flows of lava, and their mineral constitution shows that they have been greatly altered from their original mineral composition, though the alteration seems to be too great and uniform to be attributed to the influence of the overlying lava.

Outcrops of the lavas of this group have been met with as far north as the latitude of Gamopedi, but the rocks certainly extend further north through country which has not yet been examined. In the last Annual Report descriptions were given of seven synclinal basins of this group, but one of these, the so-called Lucas Dam syncline, has been found not to be a syncline; the supposed overturned western limb has been examined again, and followed northwards nearly to the north end of the Langebergen, where it becomes hidden by superficial deposits. Throughout its known length, about 55 miles, the Ongeluk volcanic rocks dip under the Upper Griqua Town beds In the Kuruman district the Vlak Fontein syncline disappears; the Ongeluk lavas of Vlak Fontein become continuous with those stretching northwards from Lucas Dam, and together they form a wide stretch of undulating ground south of the Gamagara valley. This piece of ground is but thinly covered with superficial deposits, and is comparatively well populated by Europeans, as the veld is healthy for stock and water is got at moderate depths. The volcanic rocks are certainly continued far to the north of Gamagara, but they are buried under limestone. It seems likely that they are continuous round the north of the Kathu Forest with the Ongeluk beds lying west of the Kuruman hills. These latter beds were seen for the last time cropping out below surface limestone down the dry valley which traverses Cowley and joins the Gamagara valley near Honig Draai. There is no sign of the reappearance of the Lower Griqua Town beds of the Kathu hill to the north. The Ongeluk beds west

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of the Kuruman hills in the neighbourhood of the Kathu road have probably been separated from the Dimoten syncline by denudation, though the lavas have only been completely removed over two or three miles of sandy ground on Clumber.

The Dimoten syncline is similarly separated from the Good Hope (Barkly West) outliers, and these again from the large Ongeluk-Witwater syncline. During the past year the mapping of the latter syncline was completed, and that of the Abrams Dam and Leelyks Dam syclines was continued, but the latter are much obscured by sand.

So far as the general nature and relations of the Ongeluk volcanic rock to the lower beds are concerned, there is nothing to add to the account given on pp. 180-184 of the 1905 Report, though the past year's work has confirmed the opinion that these rocks follow conformably the banded magnetic and glacial deposits of the (Lower) Griqua Town beds, and has shown that the character of the lavas is constant as far as they have been followed—over an area which extend 130 miles from north to south and 40 from east to west.

Some further thin slices have been cut from these rocks. A lava from one of the Good Hope outliers (1583) is seen under the microscope to have a considerable amount of brownish nearly isotropic base, which looks dusty under a high power, owing to the presence of great numbers of opaque granules; part of the base, which certainly used to be glass, contains small clear spherulitic aggregates of a weakly refracting and polarizing mineral, and grains of calcite. The well-developed minerals are:—(1) Pseudomorphs of bastite after enstatite in small porphyritic crystals; (2) augite in grains and small irregularly-developed crystals; and (3) felspar in very small lath-shaped sections. The structure is that known as hyalopilitic. Another slice from a Good Hope outcrop (1584) shows a similar rock, in which the constituents reach larger dimensions. There is much glass; a rather basic plagioclase appears as thin laths and skeleton crystals. Augite is very abundant in long ill-developed twinned crystals, sometimes enclosing felspar; bastite pseudomorphs are also seen. Amygdales of chalcedony are present. A very similar rock was got from Kort Kloof Fontein (1594). Two sections (1585, 1586) were cut from a rock which closely resembles the Ongeluk lavas in the field, but which was mapped as an intrusion lying south-west of the Good Hope outliers and at a lower horizon in the Griqua Town series. Its appearance under the microscope confirms the field-evidence. It is a holocrystalline rock, consisting of much-altered felspar, augite, enstatite, iron ores, and a small quantity of fresh brown hornblende, biotite and quartz. The felspars are almost entirely represented by aggregates of small brightly-polarizing flakes, and are often enclosed by ophitic plates of augite, which also encloses the enstatite. Part of the enstatite is changed to bastite, but much

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is still fresh, especially in (1580). The brown hornblende occurs in continuity with some of the augite. There can be little doubt that this mass of rock is an intrusion from the same magma that supplied the extrusive volcanic rocks of the Ongeluk series. A similar rock, which has not however been examined microscopically, forms a large intrusion in the Groen Water area.

An amygdaloidal rock from M. 35 · Hay has a glassy base (1592), which is crowded with feathery crystallites like those mentioned on p. 184 of the 1905 Report, and taken to be an amphibole. In this section, however, and in (1596) from Punt, the extinction angles are too large for amphibole, and the mineral is probably a monoclinic pyroxene. The felspar crystals are altered to aggregates of brightly-polarizing flakes; they are sometimes porphyritically developed. Augite also occurs in irregular patches enclosing the pseudomorphs after felspar. Enstatite is represented by bastite pseudomorphs. Amygdales of chalcedony are abundant.

A rock from Langar, in the Kuruman district (1617), shows a once glassy base, now changed to a mass of feathery crystallites, together with small patches of finely crystalline quartz or chalcedony. Pseudomorphs after small porphyritic felspars and skeleton forms of felspar lie in the ground mass. Augite and enstatite were not determined.

A lava from Goup, Hay (1599), is a fine-grained rock made chiefly of minute felspars and augites without porphyritic crystals. The indeterminable base includes some chalcedonic silica.

A rock from a well on Hartfeli, Hay (1603), is rather similar to (1599), but has more ground mass, which seems in part to be glass; it also has a few porphyritic felspars and bastite pseudomorphs. The small felspars are not often twinned, but some larger twinned crystals give symmetrical extinction angles up to 19°, which indicates labradorite. The low extinction angles on the untwinned microlites measured (under 6°), indicate the presence of a more acid plagioclase. From a second well on Hartfell a nearly holocrystalline rock was obtained (1602); the ground mass is of felspar with some chalcedonic silica. Ragged plates of augite enclose felspars, chiefly represented by pseudomorphs. Bastite does not occur in well-shaped pseudomorphs, but in patches enclosed by augite. This rock is more like the Good Hope intrusion than a lava, but its field relations cannot be made out.

All these igneous rocks have a strong family resemblance, and are like those described last year from the Juanana syncline (1905 Report, p. 184, etc.). They are different both in texture and composition from the Ventersdorp lavas, and from those in the Middle Matsap beds. At the present time a thorough comparison with the igneous rocks, apparently intrusive, in

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the Pretoria series of the Transvaal cannot be made, but it should be noted that the rhombic pyroxene which is certainly characteristic of the Ongeluk igneous rocks may point to a relationship with the norites of the Transvaal, though the rhombic pyroxene in the latter[1] is chiefly at least hypersthene, a pleochroic mineral probably containing more iron than the enstatite of Hay and Bechuanaland. Lately a volcanic tuff has been found in the Pretoria beds,[2] though no lavas have been described from them. Rocks like the elaeolite-syenites of the Transvaal have not been found in Cape Colony.

The maximum thickness of the Ongeluk or Middle Griqua Town beds has not been estimated with any approach to accuracy. It is probably considerably over 1,000 feet in the Lucas Dam area.

(3) *The Upper Griqua Town Beds.*

These beds have only been found on the west side of the area formed by the Ongeluk volcanic series between Floradale (Hay) and Alister, in Kuruman. The narrow strip of country which they occupy is largely covered with sand, but the lower beds in this group are hard, and appear in long low sharp ridges between the Ongeluk volcanic rocks and the Lower Matsap group. The southernmost part of the strip was described in the 1905 Report (pp. 171, etc.), and the conclusion arrived at was that the beds belong to what is now called the Lower Griqua Town group. The reason for that conclusion was that the brown magnetic jaspers with thin limestones are very like similar beds below the glacial boulder beds, and though the latter rocks were not found *in situ* west of Lucas Dam, etc., pieces of a cherty boulder rock were found, together with a few loose pebbles, which have striations on their surface. On this evidence the beds in question were regarded as being on the overturned western limb of a syncline. There were difficulties involved in this view, especially in connection with the change in character of a great part of the supposed Lower Griqua Town beds and their relation to the quartzites and conglomerates to the west, which were then not understood so well as they now are after further work.

Last year's work showed that the conditions observed on Floradale and Lucas Dam hold good as far north as the beds were seen, *i.e.*, that along the 55 miles of boundary yet examined the jaspers and slates dip at fairly high angles westwards and away from the Ongeluk lavas, and that they are followed by the Lower Matsap group. The dip of the Ongeluk beds is usually difficult to determine, and especially so in an area, such

[1] See Rep. Geol. Surv. Transvaal for 1904 and 1905, especially 1905, p. 72-76, also J. A. L. Henderson, "On certain Transvaal Norites etc.," London, 1898

[2] A. L. Hall, Rep. Geol. Surv. of Transvaal for 1905, p. 53.

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as that along the western side of Lucas Dam, etc., where they do not make bold outcrops. Were this an overturned limb of a syncline, one would not expect to find such regularity of dip along such a considerable distance; somewhere the beds would probably be found to dip normally under the Ongeluks. Then again, the many further outcrops examined bring out differences from rather than resemblances to the Lower Griqua Town beds. No outcrops of a glacial conglomerate have been met with, though that part of the group nearest the Ongeluk lavas is fairly well exposed on Mamaghodi and Cox. Throughout the known range of these beds they include a large thickness of slatey rocks quite unlike any yet found in the Lower Griqua Town beds of Hay and Bechuanaland. Some of the slates, however, are like those shaly beds seen near the top of the Lower group on Rooi Laagte, in Hay (1905 Report, p. 161).

West of Lucas Dam house, the total thickness of the Upper Griqua Town beds is rather over 2,500 feet, provided that the concealed ground does not include rocks with very different dips to those observed. Near the Ongeluk beds there are some 200-300 feet of rather massive brown, red, and black magnetic cherty beds, with which thin blue limestone is interbedded, then follow soft slatey rocks infrequently exposed; about 400 feet above the base of the group is a dull greenish black argillaceous rock with quartz grains and a thin white quartzite; then follow slates, including blue phyllites. Amongst those slates there are obscurely spotted rocks. The contact with the overlying Matsap beds is not exposed.

On Lyn Puts (Mapedi) a similar section can be made out, but there are 200 feet of light-coloured quartzites above the jaspers, in place of the thin bed seen on Lucas Dam. The phyllites are better seen on Lyn Puts; a specimen containing long crystals was sliced for microscopic examination (1664), and it is seen to be made of a doubly refracting ground-mass with very much indeterminable dusty material; the crystals are ill-defined, and penetrate each other as if twinned; their substance is replaced by small grains of calcite, two very weakly polarizing minerals, of which one is chlorite in small grains, quartz, and occasionally epidote. Similar rocks with spots and crystals were seen in a corresponding position on Tlhokalechogo, Venn, Tomkins, Murray, and Lewis.

The belt of ground occupied by these Upper Griqua Town beds becomes slightly wider northwards from Floradale, but it is uncertain whether there is a considerably greater thickness of rock between the Ongeluk and Matsap beds there than at Floradale. South of Floradale the superficial deposits hide the boundary for many miles. East of Pauw Fontein there is no room for the Middle and Upper Griqua Town beds between the Lower Matsap and the typical banded jaspers of the Lower Griqua Town group.

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VI. THE MATSAP SERIES.

This group of rocks can now be divided into three sub-divisions:—

The Upper beds; chiefly quartzites and sandstones, which build up the Langebergen proper.
The Middle beds or Hartley Hill group; quartzites, lavas, and fragmental rocks of volcanic origin.
The Lower beds; quartzites, slates, and conglomerates forming the foothills on the east of the Langebergen north of Pad Kloof.

The work which showed the convenience of introducing this threefold division of the series was done in the south-west corner of Bechuanaland and the north-west of Hay. It is not yet possible to discuss fully the suitability of the arrangement to the rocks as they exist south of Pad Kloof, in the area surveyed in 1905, and in Prieska, but some remarks will be made in connection with that matter.

It will be convenient to describe the occurrence of these rocks under three heads:

(*a*) The outliers in the Koegas Field-Cornetcy.
(*b*) The faulted outlier of the Gamagara ridge.
(*c*) The Langebergen north of Pad Kloof, and the western and eastern foothills.

(a) The Outliers in the Koegas Field-Cornetcy.

An outlier of the Matsap beds on Dingle forms a prominent ridge, separated by red sand-covered ground from the Ongeluk lavas to the east, and from the Griqua Town beds in the long ridge which trends southwards from Downes to Duikers Dell to the west. The beds dip at 60° towards W. 20° S. They consist of purple quartzitic sandstones containing pebbles of quartz and jaspers, including bright red jasper like that in the Ongeluk beds. As a whole, the rocks are very like the beds of the Langebergen, and the isolated position of this block of apparently Upper Matsap beds requires an explanation which has not been found.

Another mass, eight miles long, extends from Bushman's Hill in a south-south-westerly direction to Spitz Rand. The beds, which are like the Upper Matsap of the Langeberg, dip at angles of 30°-40° towards W. 20° N., and are parallel to the strike of the beds in the Piljaar's Poort hills. The ridge is surrounded by sand, and its structural relations are not clear. The Griqua Town beds crop out within three miles to the south.

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(b) The Faulted Outlier of the Gamagara Ridge.

The south end of this strip of Matsap beds was described in the 1905 Report, p. 194, under the name of the Paling ridge.

The ridge extends from Paling about 23 miles northwards to Sishen. The course of the outlier is defined by the Paling fault on the west, which trends N. 3° W., and has its downthrow on the east. The Paling fault can only have a throw of 500 feet or less, except we suppose there was a renewal of movement, but in an opposite sense, along a pre-Matsap fault in post-Matsap times. The difficulty comes in when an explanation is sought for the disappearance of a great part of the Lower Griqua Town beds near the Gamagara valley, where the outcrops of the upper beds are very numerous, though the bottom part of the same group, *i.e.*, the Blink Klip breccia, crops out on the downthrow side of the fault only a mile away. The rocks are ill exposed west of the fault near the Gamagara valley, but there are sufficient outcrops to bring out the fact that a narrow band only of the Griqua Town beds exists there. Further south this strip widens, and at the extreme end of the ridge the Campbell Rand limestone crops out near the fault. It seems to me probable that there has been a renewal of movement along the fault, but in the opposite direction, as supposed above.

The width of the belt of Matsap beds is probably never more than a mile and a half. The dip is generally westwards at angles of from 3° to 30°. Easterly dips are seen on the west side of the belt, and occasionally a shallow synclinal fold is seen, as on King and Mokanning.

The base of the Matsap beds is specially well seen on Mokanning, King, and Bruce. The lowest 20 feet or so of the series are very much redder than the upper beds, doubtless owing to the amount of haematite débris got from the Blink Klip breccia, but there may also have been subsequent staining as well. There are many rounded boulders and pebbles of the heavy haematitic rocks in these lower beds, and in places the matrix of the basal conglomerate is largely made of haematite, so that the outcrop may be mistaken for the Blink Klip rock, but the great difference is that the basal conglomerate contains well-rounded fragments of the breccia, and is distinctly bedded conformably with the overlying normal beds of the Matsap series.

This ferruginous conglomerate resembles closely the exceptional kind of conglomerate seen in the anticline on the Matsap ridge described on pp. 191-2 of the 1905 Report. Similar rocks have not been noticed elsewhere, and they appear to be absent from the south end of the Gamagara ridge on Paling.

The bulk of the Matsap beds in this ridge is very much like the quartzites of the Langebergen; purplish and grey quartzites predominate, but they are not traversed by the rough cleavage that characterises the Langeberg rocks north of Pad Kloof.

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It is difficult, if not impossible, to decide which of the three sub-divisions of the Matsap series the rocks on the west flank of the Gamagara ridge belong to. They most nearly resemble the Upper group, but rocks of that type are also found in the Middle and Lower Matsap beds of the Langeberg region.

(c) The Langebergen north of Pad Kloof and the foothills.

At the time the last Annual Report was written there was doubt as to the stratigraphical position of the beds in the foothills both on the east side of the main range on Dunmurray and on the west side south of Witsands. The latter were doubtfully placed in the Kheis series, which, according to Stow, is probably the oldest group in Griqualand West. It was said in that Report that the quartzites and quartz-schists (badly exposed) of the hills south of Witsands were almost certainly older than the Matsap beds. During the past year the western foothills from near Pad Kloof northwards to the Gordonia boundary have been examined, and so have the eastern foothills from Wyd Poort to the north end of the Langebergen. The exposures in Kuruman (*i.e.*, South-western Bechuanaland) are better than those in Hay, and they led me to the conclusion that all the foothills both on the east side of the main range on Dunmurray and same great group which builds up the latter.

The foothills west of the main range on Andries Fontein are made of quartzites and grits, with occasional red jasper pebbles; they are rather more schistose than the Langeberg rocks, but their strike is parallel to the latter. Further south towards Witsands the foothills beds are paler in colour than the bulk of the Langeberg quartzites, but they lie nearly parallel to the latter. They resemble quartzites in the Lower Matsap beds east of the Langeberg. The divergence of strike south of Matsap noted in last year's Report is not yet explained. The rocks only crop out in the ridges along here, and on the east of the main range the same is the case. Intervening low ground from half a mile to four miles wide is sandy, and wells are very few, so the structure is difficult to make out. Till the country west of the main range is fully traversed the question of the precise stratigraphical position of the western beds must remain open. The dip of beds in any one ridge does not help much, for the rocks in the main range are repeatedly folded, and the foothill beds are also folded; so that unless a nearly continuous section can be found the isolated dip observations do not settle relative stratigraphical positions.

In the last Annual Report it is stated that jasper pebbles were not obtained *in situ* in the conglomerates seen near Lucas Dam, but further examination has shown that such pebbles are present, and that in some localities they are fairly abundant.

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About 400 yards south of the gate on the west side of Lucas Dam, and situated on the farm M. 104 (part of the Dunmurray estate), there are three bands of conglomerate in the Lower Matsap beds exposed by a long cutting. The matrix of the conglomerate is quartzite, and the intervening beds are chiefly reddish and greenish quartzites and grits, but there are also sandy slates and silky phyllites. The pebbles in the conglomerates are in most cases quartzite and quartz, but there are also pebbles of red jasper, a dark green diabasic rock, and a granite with large flakes of muscovite. The sandy slates and phyllites are not exposed on the hillsides generally, for they are covered with fallen débris from the hard beds. The quartzites below the conglomerates are usually light in colour.

These easternmost foothills rise to a height of about 1,000 feet above the flat ground to the east of them on the western side of M. 91 (Hay) and Mapedi (Lyn Puts) in Kuruman. They form a range stretching from Young in Kuruman, about 40 miles southwards, to O. 231 in Hay, but there are gaps where the rock sinks below the sand at several places in their course, and south of O. 231 they are not seen again, unless one of the outlying ranges in the Koegas Field-Cornetcy represents them. North of Young they do not appear, but from the top of the Langebergen near Toto I saw similar foothills east of the Korannaberg.

On the eastern side of O. 209 (Pauw Fontein), some 20 miles S.S.W. of the last appearance of the foothills, prospecting trenches have been made in gently undulating gravelly ground, and in one of these two bands of coarse quartzite conglomerate have been exposed; they contain pebbles of quartz, quartzite, and red jasper. The conglomerates are from three to four feet thick, and are interbedded with quartzites and green schistose slates; they dip W. 20° N. at about 45°, towards some volcanic rocks exposed in a cutting west of them. They are almost certainly part of the Lower Matsap group. The change of strike, which is about N. 5° E. near Lucas Dam, agrees with the similar change in the main range noted in the last Annual Report; N.N.E. at Bakens Kop, and more and more nearly north towards Andries Fontein.

As explained when dealing with the Upper Griqua Town beds, there is difficulty in drawing a boundary between the latter and the Matsap group in northern Hay and southern Bechuanaland, for the Upper Griqua Town beds are ill exposed, and the strikes of the two series are nearly or quite parallel. It is certain, however, that in the south of Hay, as well as in the Paling and Matsap ridges, the Upper Griqua Town beds do not intervene between the Matsap beds and whatever happens to underlie them. At the present time the Middle Matsap beds have not been recorded south of Paauw Fontein, so that there is a doubt as to the identity of the base of the Matsap series throughout

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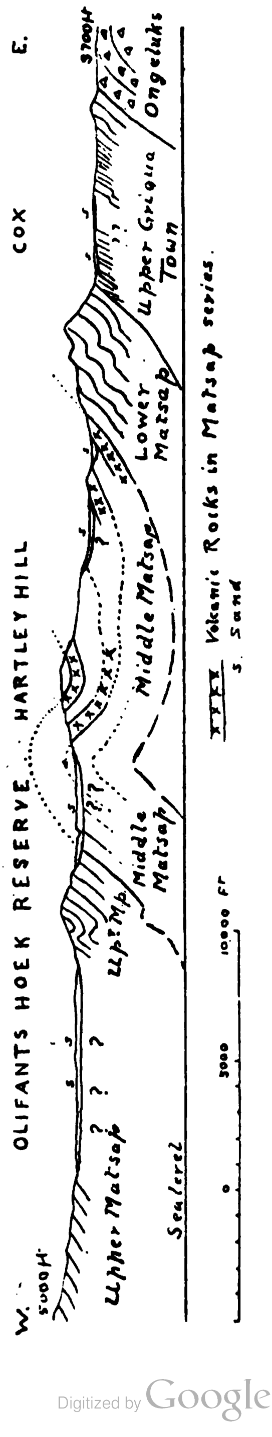
Hay and Prieska. It is likely that the line taken as the base of the series in the eastern foothills last year, *i.e.*, the bottom of the first quartzite or grit met with when going westwards from the jasper and slate rocks of the Upper Griqua Town beds, will be found to be very near the true base in this area.

The strike of the Lower Matsap beds on Paauw Fontein is N. 20° E., where next seen on O. 231 it is N. 150° E., on Vogel Water it is N. 10° E., on Lucas Dam N. 50° E., north of the Bechuanaland fence on Mapedi it is north and south, but on Tlhokalechogo it turns to N. 5°-10° W., on Mamatlui, Tomkins, and Hartley it remains about N. 10° W., but in the low kopjes in which the formation makes its last appearance, so far as last year's work was concerned, on Neylan, Cox, and Young, the strike is about N. 25° W. This general bending of the strike corresponds closely with the bending of the Langebergen a few miles to the west.

The thickness of the Lower Matsap beds in the north part of Hay cannot be less than some 3,000 feet.

The line dividing the Lower from the Middle Matsap beds is drawn below the lowest lava or distinctly ashy rock, and the line between the Middle and Upper beds is drawn at the top of the highest lavas or ashy beds. The quartzites included between these limits are in part white and green, and these beds are unlike the great mass of rock forming the Upper Matsap beds as defined here; but there are purple grits and quartzites also, probably these are thicker than the green and white beds. If the volcanic rocks disappear along the strike there will be no means of distinguishing the three sub-divisions, except by the presence of slates and conglomerates in the lowest sub-group.



Difficulties of this sort must always be encountered where lithological characters alone are taken as the basis of classification, but it seems better to make use of such characters in a thick group of rocks like the Matsap series than to leave the series undivided.

The Middle Matsap beds are best seen on the Olifants Hoek Reserve and Hartley, where their outcrops are repeated by folding. They have been followed 9½ miles north of Olifants Hoek, as far as the farm Dalgetty, and the outcrops are fairly numerous in that direction. South of Olifants Hoek they have been traced at moderate intervals as far as M. 102 in Hay, but from there only one outcrop was seen, on O. 231, till the southernmost exposures, in 4 prospecting pits, are met with on O. 209 (Pauw Fontein). If intervening outcrops exist they are cut flat with the plain east of the Langeberg in this region. The whole distance from Dalgetty to Pauw Fontein is about 60 miles.

The best exposures near Olifants Hoek are on the hills between that Reserve and Hartley. The section in Fig. 7 shows the general relations of the volcanic rocks and the quartzites, etc. There are wide stretches of concealed ground in the course of this section, but less than along any other line that I could

FIG. 8.—Section through a hill about 300 feet high in the north-east part of Olifant's Hoek Reserve.

1. Blue lava
2. White quartzite.
3. Blue lava.
4. Blue gritty tuff.
5. Green quartzite.
6. Blue lava.
7. Blue tuff.
8. Blue lava.
9. Blue-green tuff.
10. Green quartzitic tuff.
11. Blue-green breccia and tuff.
12. Purple quartzite.
13. Sand.

have examined. The section is drawn approximately to scale, and the thicknesses of some of the various rock groups as represented are not far from the truth unless there are undetected faults which increase the apparent thickness; folds will do the same, and in great bodies of uniform rock, as that on the west of the section, folds are difficult to discover, and it is impossible to gauge their effect without making a detailed survey. The Upper beds, therefore, are certainly not so thick as they appear in the section.

There are two volcanic bands in the section; but each of these has more usual types of rock in it.

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The section in Fig. 8 represents the structure of a hill on the north-east part of the Reserve, where the intercalation of lavas, ashes, and quartzites is well seen.

On the east side of Hartley the Middle group is seen lying on the quartzites and conglomerates of the Lower group. It commences with a coarse conglomerate which has a dark green ashy matrix; this conglomerate is several feet thick, and above it are less conglomeratic beds; all these are well bedded rocks. Above them lie dark green breccias, which do not contain the quartzite, quartz, and jasper fragments seen in the conglomerates below, and lavas. There are some 600 feet of the lavas and breccias exposed, and the conglomeratic beds below, together with interbedded quartzites, bring the thickness of the part of the Middle Matsap beds exposed on these hills up to nearly 1,000 feet. These beds are separated by sand from the nearest outcrops westwards of them, and the greater part of the Lower Matsap beds is hidden on this, the eastern, limb of the Hartley hill syncline. An interesting section shows the gradual passage from green breccia or tuff into the usual purplish quartzites of the Matsap series. A slice cut from a piece of the transitional rock (1665) shows much quartz and chert in well-rounded grains up to 2 mm. in diameter. The matrix is made of epidote, chert, calcite, and dusty matter like powdered devitrified glass. There are pieces of scoriaceous devitrified glassy lava nearly opaque with this dusty matter.

The gritty quartzites of this neighbourhood and the green ashy beds are affected by a rough cleavage, which trends S. 15° W. The cleavage is like that seen in the main range of the Langebergen, and it obscures the dip, for the rock yields to weathering along it rather than along the bed planes, which strike in more or less the same direction, but have a much lower inclination than the cleavage. In spite of the cleavage, the synclinal structure of the Hartley hill rocks is well seen from the north; and the dark ash beds and lavas bring out the structure very clearly in certain parts.

At the north end of these hills, near the north-eastern beacon of the Reserve, the volcanic rocks are well exposed. The beds represented in the section Fig. 8 belong to the lower of the two volcanic bands, and are almost certainly part of the beds lying just above the basal portion of the Middle Matsap group described above. A slice cut from the uppermost tuff (11 in Fig. 8) shows (1667) round grains of quartz, chert, and felspar lying in a rather opaque green matrix, which contains also recognisable plagioclase felspar laths; the bulk of the matrix cannot be separated into its constituents under the microscope, but chert and epidote are distinguishable, and a great quantity of very small needles of a greenish mineral, and also opaque iron ores. A slice of a vesicular lava (8 in Fig. 8) shows much blue-green hornblende in allotriomorphic crystals, partly changed to a

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chloritic mineral, faint outlines of the original felspar laths, now much altered, iron ores and sphene, chert, epidote and actinolite. The last two minerals are products of the alteration of the original constituents; the chert may be an addition from outside; and together they now make up the bulk of the rock. The vesicles are filled with chalcedony, epidote, and calcite (1668). The volcanic beds of this hill are separated by some 500 feet of quartzites from the higher band of volcanic rocks exposed on the face of the high hill east of Olifants Hoek Police Camp. The lowest green beds are ashes; as in almost all of the Matsap ash beds, a conspicuous feature on a broken surface is made by the fractured quartz grains plentifully scattered through the rock; they are as much as 1-2 mm. in diameter, and they are well rounded; there are similar grains of chert and a few of felspar, which looks like a felspar from granite, for it is either twinned acid plagioclase or microperthite. There are small pieces of vesicular lava with calcite and chloritic amygdales; the finer grained part of the rock is a mixture of epidote, calcite, and chert (1662). Two slices have been cut from lavas exposed on this hill (1623, 1625), but there hardly any of the original characters of the constituents are recognisable. The rocks are made of epidote, chert, actinolite, sphene, and a little calcite. Some iron ores are the only constituents which may be original. The steam holes are filled with epidote, chalcedony, and chlorite.

A slice (1624) from a vesicular lava fragment taken from a breccia on this hill shows the outlines of felspar laths now represented by chlorite, calcite, and cherty silica lying in a green matrix clouded with dusty matter. The vesicles are filled with chalcedony and epidote.

North of Olifants Hoek it seems probable that the syncline shown in Fig. 7 disappears, and that there is a more or less continuous upward succession from the base of the series on Lewis to the middle of the main range near the trigonometrical beacon Langeberg (6,011 feet). That this is probably the case is shown by the narrowing width of the ground which the Lower and Middle groups occupy as one goes northwards from Olifants Hoek. On O'Donoghue the lower part of the volcanic beds is buried, but amygdaloidal and compact lavas and ash beds are seen. A slice from one of the lavas (1669) shows rather large ill-developed crystals of blue-green hornblende, often twinned on the orthopinacoid plane; no felspar is visible, and the bulk of the rock consists of chert, epidote, actinolite, and small grains of sphene.

On Puduhuish, Toto, and Dalgetty there is a range of kopjes made of volcanic rocks, but their position in the series is not certain. The best section is probably seen on Puduhuish, where the lowest visible beds are cleaved sericitic quartzites containing a few massive beds without sericite; small quartz pebbles occur in these quartzites. Above the quartzites lie 600 feet of gritty

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dark breccias and tuffs, then come 70 feet of quartzites with pebbles, overlain by 250 feet of dark-coloured lavas, breccias, and a few bands of quartzites, 400 feet of tuffs and lavas complete the section as far as the volcanic rocks are concerned; some 200 feet of purple quartzites are seen above the volcanic rocks, and a wide flat devoid of outcrops lies between the westernmost kopje and the Langeberg.

South of Hartley and Olifants Hoek the Middle Matsap beds are exposed on Gaston and Tomkins, and again on Mamatlui; the rocks are much hidden on these farms, but a well sunk on Mamatlui reveals a coarse conglomerate, with boulders and pebbles of quartzite, red and black magnetic jaspers, quartz, slate, and green diabase in a tuffy matrix. Outcrops of amygdaloid and tuff occur within 200 yards of the well.

Further south the Middle group makes outcrops on M. 102, where a low ridge of volcanic rocks projects from the sand. The lowest rocks seen are blue-green epidotic lavas and tuffs, above which lie grey quartzites about 4 feet thick, with numerous boulders of quartzite, chert, and lavas up to a foot in diameter, all well rounded; 200 feet of blue porphyritic lavas lie on the conglomerates, but no further outcrops were seen till the usual purple quartzites of the series were met with about half a mile to the west. The porphyritic lava is unlike any rock in other outcrops of this group yet examined; a slice (1663) shows that the felspar crystals are completely altered into a mass of minute minerals; the ground mass shows faint indications of the original small felspar crystals, but it is now made almost entirely of chert, epidote, actinolite, and calcite. A few quartz grains occur; they are angular or quite rounded, just like the quartz grains in the Matsap tuffs and quartzites; they were probably picked up by the lava or dropped into it during its flow, and are not the remains of corroded porphyritic quartz crystals.

The conglomerate is seen under the microscope (1661-2) to consist of rounded masses of chert, lavas of the types found in the Matsap volcanic series and described above, and a few pieces of marble embedded in a gritty matrix in which round quartz grains are conspicuous; the fine grained part of the matrix consists of epidote, calcite, actinolite, and chert. This rock was evidently derived from the waste of a volcanic area, and could hardly have been formed unless there was a land made of the Matsap volcanic rocks; so it proves a local unconformity, unless the volcanic rocks extended beyond the range of the quartzitic sediments, and thus provided débris during and after the eruptions. At the present time no evidence has been found of a considerable unconformity within the series.

The volcanic rocks crop out again about a mile north of the road from Dunmurray to Floradale, on the farms M. 100 and O. 231. Some 500 feet of green amygdaloids and fine tuffs like

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those of Olifants Hoek are seen here. The outcrops are separated from the purple quartzites to the east and west by wide strips of sand.

The southernmost exposures of the volcanic rock yet found are on O. 209 (Pauw Fontein) and O. 212. They are in cuttings north-west of the conglomerates mentioned on a previous page in connection with the Lower Matsap beds. Two sections (1658, 1659) have been cut from the lavas on Pauw Fontein; they are from amygdaloidal rocks, the vesicles being filled with chalcedony, chlorite, and epidote; felspar is present in partly altered lath-shaped sections of small size, it has low extinction symmetrically about the twin plane; the rest of the rock consists of epidote, chert, and iron ores in very small grains; there are no porphyritic constituents.

No important details as to the stratigraphical position of these lavas are available, but the fact of their occurrence west of the westward dipping conglomerates, quartzites, and phyllites of the other cutting is enough to show that they belong to the Middle Matsap group as defined above, and they are similar in character to the Olifants Hoek and Hartley lavas.

The thickness of the Middle Matsap beds is very considerable, perhaps as much as 4,000 feet.

Comparison of the volcanic beds of the Matsap series with those in the Griqua Town series and the Ventersdorp beds.

As there are now three great volcanic groups older than the Karroo system known from the country north of the Orange River, it is desirable to point out briefly the chief characters that distinguish the Matsap lavas from those belonging to the other groups. So far as the Matsap lavas are yet known, they are the most altered of the three, although they are the youngest. They are decidedly less acid in composition than the Pniel rocks, which are again much less acid than the Beer Vley and Zoetlief lavas. They contain little, if any, original quartz, the cherty silica now seen in them is very probably all of secondary origin, whereas the Ventersdorp diabases very frequently contain quartz in micropegmatite, and the more acid lavas (Beer Vley and Zoetlief) have quartz crystals porphyritically developed, as well as quartz in the ground mass. The Matsap lavas are unlike those of the Ongeluk group both in having no pyroxene phenocrysts and in the nature of the ground mass, though the former are so greatly altered that a former glassy or andesitic base may not be clearly recognisable. The few specimens which show remains of small felspar crystals indicate that the ground mass may have been of the sort called andesitic.

The presence of blue-green hornblende in two of the lavas examined would seem to separate them from the older lavas. This hornblende looks like an original mineral and not uralitised augite.

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No analysis has been made of the Matsap lavas, and their great alteration makes it impossible to give them a name which has a precise signification, but they seem nearer the hornblende-andesites than any other large group of rocks.

As in the cases of the older volcanic beds, there is as yet no indication of vents or fissures through which the Matsap lavas and tuffs were extruded.

Mr. Mellor[1] has described volcanic rocks from the Waterberg system of the Transvaal, of which the Matsap beds are supposed to be the equivalent. It is obvious from the accounts referred to that the Transvaal volcanic rocks of this age are more acid than the Matsap volcanics; nothing approaching a rhyolite has been found in the latter.

The Upper Matsap beds form the main range of the Langeberg and some large hills lying east of it, such as those on Makala, Thabaletseli, Dunmurray estate, and Wyd Poort. They consist of a thick mass of very uniform quartzitic rock, purplish in colour, containing scattered pebbles of quartz and jasper. The chief difference between parts of this rock is brought about by the presence of more or less argillaceous and sericitic materials, but these do not occur abundantly enough to give rise to slates or phyllites; the quartzites become distinctly cleaved where there is a perceptible amount of the sericitic or clayey matter. In many sections false-bedding is strongly developed.

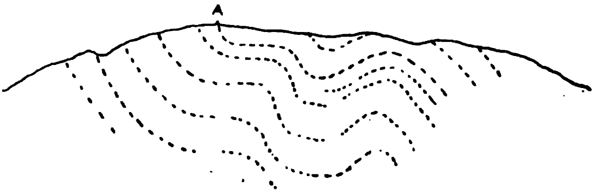

FIG. 9.—Diagrammatic sketch of the hill on which the Trig. beacon Langeberg (A) stands (6,011 feet), showing the flexures in the Upper Matsap beds. Drawn from the hill to the north which reaches about the same height.

Where a large steep slope can be seen, as on Puduhuish near the Langeberg beacon (see Fig. 9), large folds can be clearly seen. Similar sections, but not on such a large scale, are exposed in several kloofs south of Andries Fontein. Generally, however, the folds are not visible, and very detailed work, which cannot be undertaken at present, will be required before the course of the beds can be accurately laid down on a map or on a transverse section across the range. The difficulty is to recognise beds again after losing sight of the outcrop. There can be

[1] Rep. Geol. Surv. of the Transvaal for 1904, p. 56; 1905, pp. 87-89, Trans. Geol. Soc. S. A., Vol. VIII, 1905, p. 38, etc.

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no doubt that the whole range from Pad Kloof to Matesang is made of folded beds, and therefore of a thinner group of rocks than one would suspect from several traverses, when occasional good outcrops alone are seen. The rough cleavage dips westwards and tends to obscure the dip of the beds.

VII. The Dwyka Series.

The Dwyka series is the only member of the Karroo system (excepting intrusive dolerite) found in the area we are now concerned with. It occurs on the east of the Griqua Town escarpment, south of the village of that name, in the wide valley east of the Langeberg, near Pad Kloof, and near Vryburg; the last-named locality was described by Mr. du Toit in the 1905 Report.

East of the Griqua Town escarpment the Dwyka beds were only seen in the valley of the Sand River, which runs south-east to the Orange River; they there form part of a large area lying to the east, and but little information was got about them. They certainly lie upon the Campbell Rand and Griqua Town series at a somewhat lower level than the general surface of the Kaap Plateau. The interesting question as to whether this Plateau is a feature dating from pre-Karroo times or whether it is entirely subsequent to that formation could not be answered from the limited area examined, but the apparently flat surface formed by tufaceous limestone of recent date, and passing from the Dwyka on to the much older rocks, gives the impression that the southern part of the great plateau is a result of post-Karroo erosion. Dwyka outliers, either lying on the flat surface of the plateau or filling valleys in it, have not been found in the country between Griqua Town and the northern edge of the plateau. On Middelwater and Elands Fontein the Dwyka boulder beds contain great numbers of dolomite and lava (Pniel series) boulders up to 5 feet in length, and a few of granite. An exposure of the underlying surface in the immediate neighbourhood of the Dwyka was not seen.

In last year's Report (p. 196) an outlier of boulder grit was described from Piljaar's Poort, in the south of the Langebergen. A much larger outlier, of which the boundaries cannot be laid down owing to the presence of a thick sandy soil, occurs on Plaatjes Dam, near Pad Kloof, and extends northwards at least as far as Pauw Fontein (O. 209). Evidence of the occurrence of boulder beds was only seen on Pauw Fontein, where a well, now filled in, had been sunk on them, and pieces of typical mudstone, with pebbles of various rocks, together with a few scratched stones, lie about the spot. About half a mile west of the filled up pit another well is down 50 feet in yellowish shales, but the boulder beds were not reached. At Plaatjes Dam a well was dug 100 feet into grey shales lying horizontally without reaching

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the bottom; on the right bank of a stream bed from the Langebergen similar horizontal shales are exposed, and they contain thin layers of fibrous limestone, with the fibrous structure perpendicular to the bedding. Limestone of this character is met with in the Dwyka formation in the Vaal River[1] valley and in the south of Cape Colony. There is little but the mere occurrence of these rocks to record, but they show that in Dwyka times the valley east of the Langebergen in this neighbourhood was deeper than it now is, and that the existing wide and flat valley is cut out of pre-Karroo rocks as well as those of Dwyka age, for the Pauw Fontein Matsap outcrops mentioned on a previous page are on about the same level as the top of the wells in the Dwyka formation, or only slightly higher.

VIII. Intrusive Rocks.

There are many dykes and a few other bodies of intrusive igneous rocks in the area surveyed. No intrusions of typical acid rocks, such as granite, were found; the granite described on a previous page may be called the basement rock of the district, and the sedimentary beds which it invaded have not been found within the district.

It will be convenient to describe the rocks according to their petrographical type, as it is not possible to decide with certainty the age of several of them. In fact, in no single case can the age be determined precisely, for a later limit is difficult to ascertain. The petrographical character of certain masses enables one to say that they belong to the same great group as the intrusions which occur in the Karroo formation throughout a very large area in the Colony; and the nature of other intrusions shows that they belong to the Pniel, Ongeluk, or Matsap volcanic groups.

(1) *Basic and intermediate rocks other than Karroo dolerites.*

In the Middle Matsap beds near the north-east corner of Olifants Hoek there is a small but conspicuous mass of a rather coarse-grained quartz-diabase. Though associated with the Matsap volcanic rocks, its characters are so different from those of the lavas that it cannot at present be regarded as belonging to the same group of rocks. Beyond the fact that it is intrusive in the Middle Matsap beds, its age has not been fixed. It differs considerably from the Karroo type of dolerite. It forms a short thick dyke about half a mile long and some 300 yards wide, trending east and west, but slightly concave towards the south. A thin section (1666) shows that it is of felspar, augite,

[1] R. B. Young. "The Calcareous rocks of Griqualand West." Trans. Geol. Soc. S.A. Vol. IX, p. 63. Said there to be in the Ecca series, but these beds at Schmidt's Drift, etc.) belong to the Dwyka as defined by the Cape Survey.

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hornblende, quartz, ilmenite, sphene, apatite, and alteration products. The felspar is of two kinds; one variety, which occurs in stout crystals, with partly idiomorphic outlines, is almost entirely changed to a mass of epidote, zoisite, sericite, and some colourless weakly polarizing mineral, but a few patches are left, in which twin lamellae are seen; these crystals are surrounded by untwinned fresh felspar, which is often in optical unity with the felspar in neighbouring areas of micropegmatite. The latter, together with quartz without intergrown felspar, forms a considerable part of the one slice cut. The augite is cloudy, owing to the great development of a fine basal striation; it occurs in irregular patches, which do not enclose the felspars; it is often edged with green strongly pleochroic hornblende. The latter mineral also occurs alone, and in that case shows prism faces in some instances; it is certainly an original constituent. Sphene, ilmenite, and apatite are fairly abundant. The ilmenite occurs in patches with a reticulate structure, plates of ilmenite intersect each other at 60°, and the interstices are filled with a semi-opaque mineral like that called leucoxene. No mica is visible, but some chloritic pseudomorphs look as if they represent biotite. There are also pseudomorphs of chlorite and actinolite after augite. Epidote is abundant.

A thin dyke of compact dark blue rock traversing the Middle Matsap beds on Olifants Hoek is seen in thin section (1621) to consist almost wholly of felspar and blue-green hornblende. The felspar occurs in two ways, in small laths in the ground mass and in larger porphyritic crystals. The symmetrical extinction angles on albite-twins reach 20°. The hornblende is a pleochroic bluish-green variety, like the original hornblende in the Matsap lavas; it does not show crystal faces, but it occurs in small areas between the felspars, often being applied to them as the augite is in ophitic dolerites, though the hornblende in this rock is never in large enough patches to enclose the felspar. Iron ores and sphene are present. The rock is certainly allied to the Matsap lavas.

A coarse gabbro-like rock occurs as an intrusion in the Campbell Rand series on Klip Fontein, Hay. It is exposed in a prospecting hole, and its shape cannot be seen. The specimen examined is much altered, though it came from 50 feet below the surface. In a thin section (1610) it is found to consist of generally irregularly shaped pieces of colourless augite, embedded in a mass of saussurite. The original felspar is no longer visible. The augite occasionally shows partial crystal boundaries; it is in almost every case bordered by an edge of colourless amphibole, which often encroaches on the augite along cleavage cracks. Iron ores are the only other original constituent seen.

Intrusions related to the Pniel lavas and those of the Ongeluk beds have been noticed, and in part described in connection

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with those rocks (see pp. 17, 46.) In the areas mapped in as Ongeluk beds, there are probably many intrusions included, for the intrusions and lavas were not separated in the field. Their separation would require a re-examination of the ground, with a good knowledge of the characters of the various rocks under the microscope.

(2) *Karroo Dolerites and Related Rocks.*

Throughout nearly the whole of the large area in Cape Colony covered by the Karroo formation, intrusions of dolerite are met with; the rock is found both in dykes and sheets, but the latter form is the more abundant, at least as regards quantity. North of this area the dykes predominate, in fact, only two groups of dolerite outcrops in Hay and Bechuanaland can be regarded as belonging to a sheet; one of these occurs on Dunmore, in Hay, and the other was found on Durham, near Groot Fontein, on the Kaap Plateau, between Taungs and Kuruman. The latter forms a roughly circular area, about 1½ miles in diameter, and there is a pan on it. Whether it lies above or below the surrounding beds of Campbell Rand limestone is uncertain. A contact with that limestone is seen in a shallow pit on the east side of the dolerite, where white marble is exposed on one side of the pit and dolerite on the other. The junction for a foot or two at this place may be vertical. The rock (1613) is a rather coarse ophitic olivine-dolerite, with some biotite and a very small amount of brown hornblende. There are a few interstitial patches of devitrified glass. This rock does not contain quartz or the micropegmatite often seen in the less basic varieties of tne Karroo dolerite.

Dykes of dolerite are found almost throughout the district, but they are specially noticeable in the Campbell Rand formation. Sometimes they crop out freely, but more often they are marked on the surface by limestone "aars." "Aar" is the name used by the Boers for any feature on the surface which is very long compared with its breadth. Thus it may be applied to the outcrop of a dyke, to a low ridge of limestone, like those to be described presently, to a slight depression, probably marked by rather different soil from the surrounding veld, or to a line of country characterised by a particular kind of bush, and not easily distinguished by a stranger in the district. They are looked for and followed, because experience shows that water is usually got at shallower depths on or near an aar than elsewhere, and a large proportion of the springs occur on aars. I have not heard the line of junction between two stratified formations called an aar.

Limestone aars are often seen during a traverse of the Kaap Plateau. In some cases they may escape the notice of a stranger, but they more often attract his attention. They are low

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ridges rising from 5 to 20 feet above the general surface, and they are often marked by a denser growth of thorn trees and bushes than is found on the neighbouring veld. White surface limestone almost always crops out on them, or is seen where a track crosses them. I have seen many pits and cuttings which expose from 3 to 10 feet of loose white surface limestone in the aar. It is rarely that the cause of the aar is at once found, but on making a search by walking a mile or two along an aar, fragments or outcrops of a dyke rock such as dolerite or diabase are met with in many cases. This happened in my experience so constantly in the area occupied by the Campbell Rand beds that I now regard an aar as good evidence of a dyke. Travelling from Taungs to Kuruman (about 95 miles), one sees the first aar, lying E. 10° S., near Baas Jan, dolerite outcrops were found along it; three aars trending a few degrees east of north pass through Marea Amoet and one or more of them stretches far to the south and north; to the north it is probable that the aar which runs from Rooi Pan to Lochnagar is an extension of one of these Marea Amoet aars, though it has not been traced continuously over the 50 miles of country; dolerite outcrops were found on all of these aars. A S. 34° W. aar runs through Gakwe, and a north-south one through Schiet Fontein; outcrops of a dyke rock were not seen on these, but a short search only was made. An aar with dolerite outcrops passes north and south through Kent and Charles Puts; an E. 20° S. aar goes through Groot Fontein, and Mr. Mayers told me he had seen it on certain farms as far east as the edge of the escarpment in Barkly West; on the map this line was found to be nearly a continuation of the observed trend on Groot Fontein, where dolerite is exposed in pits along the aar; the dyke therefore probably has a length of at least 30 miles. Another aar with outcrops passes N. 20° E. through Toxteth.

In the Maremane anticlinal area an aar with many outcrops was followed for 21 miles north-north-east from Postmasburg, and a similar one seen on the same line six miles further north on Mount Huxley and Maremane is probably a continuation. Two other aars were seen on A. 23 in the same neighbourhood. The north of this area is so deeply covered with sand that aars could not be expected.

The reason why low ridges of surface-limestone accompany many dykes in the dolomite areas is that the dykes check the flow of underground water, and furnish a means whereby that water reaches the surface more easily than elsewhere; on evaporation the dissolved carbonate of lime is deposited, and as all the water here must contain lime, a larger amount of surface-limestone is formed than elsewhere in the immediate neighbourhood. Any other line along which water finds a ready passage to the surface should be similarly marked, so a fault in the

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dolomite should give rise to an "aar." Whether there is such an aar is not yet known. The only aar known to me along a fault, that of Lochnagar, is also along a dyke.

Thin sections have been cut from some of the dyke rocks. The Postmasburg dyke was referred to on p. 199 of the 1905 Report, but the nature of the rock was then uncertain. A section of the rock from Pens Fontein shows it to be an ophitic dolerite without olivine; it is quite fresh; labradorite and augite are the chief constituents, but iron ores, biotite, and brownish-green hornblende are also present, the two last named in very small quantity.

The three dykes on Marea Amoet are made by rocks of a similar nature to that just described, but they are not so fresh and they contain micropegmatite. The middle dyke of the three (1576) is the freshest, and has the smallest amount of micropegmatite in it; it contains both biotite and brown-green hornblende; the eastern and western dykes (1577 and 1575) have rather more biotite and hornblende.

Near Daniels Kuil there are at least two dolerite dykes. Sections from these on Klip Vley shows one of them (1579) to be a dolerite without olivine, and the other (1580) to be an olivine-dolerite, in which olivine is replaced by serpentine. (1580) is a very fine-grained rock, and the augite is partly in the granular form, i.e., the ophitic structure is not so far advanced as in most of these rocks. (1579) is more weathered than the other, but less than the Marea Amoet dykes.

Near Klip Fontein, on A. 23, there is a dyke of a remarkable rock, rather coarse grained, with pink felspar in it. No fresh outcrops were found, but good specimens were obtained from a prospecting shaft sunk 50 feet into the dyke. Three slices (1607-9) have been cut from it. It is a holocrystalline, rather coarse-grained rock, made of felspars, hornblende, quartz, augite, biotite, iron ores, and apatite, written in the order of their relative abundance, together with alteration products. Apatite is the only mineral which often shows crystal faces. The felspar is of two kinds, one is now much decomposed and represented by areas of cloudy material, crowded with small brightly-polarizing flakes; this pseudomorphic substance is usually surrounded by a narrow zone of clear felspar, which is occasionally twinned on the Carlsbad law, and is probably orthoclase; it is intergrown with quartz at the periphery in several cases. The other felspar is less altered and less abundant; extinction angles on the twin-plane trace in sections perpendicular to that plane range up to 17°, and it is probably oligoclase. It sometimes has its proper crystal faces, and projects into all other constituents, except iron ores and apatite. Quartz is fairly abundant and was the latest constituent, together with the felspar in micropegmatite, to solidify. The hornblende is a green, strongly pleochroic variety, and is more plentiful than augite, which occurs

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in patches in parallel crystallographic position with the hornblende. This hornblende is an original constituent; uralite occurs as an alteration product of the augite. The original hornblende also forms intergrowths with the iron ore. Biotite is present in small quantity in the slices cut, but it is in rather large plates, which are mostly converted into chlorite. Chlorite and epidote are the most frequent alteration products.

This rock is more like the quartz-mica-augite diorite that forms the Transkei "gap" dykes[1] than any other known to me, but the pink orthoclase gives it a different appearance to the naked eye. In thin section the two rocks are much alike, though the augite and mica are less abundant in the Klip Fontein than in the Transkei dyke, and sphene, a conspicuous constituent in the latter, was not noticed in the former. There is no direct evidence as to the age of the Klip Fontein dykes, other than its intrusion through the Campbell Rand series. Its similarity to the later intrusions in Kentani points to its belonging to the Karroo intrusions.

Dolerites have been found cutting through the Griqua Town beds on M. 36, Hay, near the Peiser mine, on Dunmore and on the eastern side of Lucas Dam, in the Upper group.

The rock obtained from a prospecting hole on M. 36 is probably part of a dyke; a section (1470) shows it to be a typical moderately coarse-grained fresh ophitic dolerite, without olivine, but containing brown mica and a very little green hornblende.

On the south end of M. 57 there were two specimens of rock taken from an outcrop, and from a pit near the outcrop. They are both Karroo dolerites (1467, 1468). The outcrop rock is a fresh ophitic dolerite, without olivine, but the other is a very fine-grained dolerite, in which the structure is porphyritic, owing to the presence of some felspar crystals of the size found in coarser-grained dolerites, while the augite is in small grains.

The rock from Dunmore was collected as an example of a bed of lava or fine-grained tuff, about 50 feet above the base of the Ongeluk volcanic series, but a thin section (1597) shows that it is a fresh and very fine-grained dolerite of the Karroo type, with granular augite, an entirely different kind of rock from the lavas of the neighbourhood. It came almost certainly from an intrusive sheet, of which the nature was not realised during the field work, and which is not laid down on the map. Under the microscope this dolerite is seen to contain some small patches of serpentine, but no mica; its structure is like that of the fine-grained rock on M. 57.

The only intrusive rock met with in the Matsap series of similar type to the Karroo dolerites was obtained from a well on Neylan. No outcrops were found. It is a very coarse labra-

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[1] Ann. Rep. Geol. Com. for 1901, p. 64 and Trans. S.A. Phil. Soc. vol. XIV Part I.

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dorite-augite rock, with small quantities of biotite, green hornblende, apatite, iron ores, and micropegmatite. The hornblende either fringes the augite or is enclosed by it. Only a very small amount of micropegmatite is present. The augite is partly ophitic, but occasionally a crystal face is seen. Two slices were cut from the rock taken from the one well, one (1619) is very fresh, and the other (1620) has rather cloudy felspars and augite, and its mica is greenish.

No intrusions were met with in rocks younger than the Matsap beds, but the Karroo sediments occupy such a small area that the absence of dolerite intrusions from them is of no significance.

IX. Superficial Deposits.

In many parts of this district the solid rocks are buried more or less completely under various surface deposits, which may attain a considerable thickness. A sub-division of these deposits according to their age is not yet possible; some of them are obviously in process of formation to-day, others may be of considerable antiquity. It will be convenient to describe them according to their lithological characters:—

(1) Sands.
(2) Surface quartzites and ferruginous rocks.
(3) Gravels.
(4) Limestones and associated siliceous rocks.

It will be seen that these four classes of rocks cannot be separated strictly, for there are transitional varieties between all of them.

(1) *Sands.*

In almost all parts of the district there are areas covered with sand or sandy soil, but the sand becomes more and more abundant as one travels westwards towards the Langebergen, though there are stretches of fairly level country along that range where there is but little sand.

On the Kaap Plateau not much sand is seen near the eastern escarpment, but it becomes abundant about half-way across and in the northern portion. The sand in this area is generally yellow in colour; red sand is usually met with within some ten miles of the Kuruman-Asbestos range.

On the farm Put Pan near Geluk a long water-cutting has been made through the surface deposits, and for a considerable distance the underlying rock, thin shaly beds belonging to the Campbell Rand series, has been reached. The section thus afforded is the best exposure of the sands, etc., on the Kaap Plateau that I have seen. The two sketches in Figs. 10 and 11 show the different layers exposed at places in the cutting about 400 yards apart. The surface is part of a wide grass

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plain, the soil at the top is scarcely distinguishable from the loamy material on which it rests, but it has more dead vegetable matter in it than the underlying sand. The sand contains a considerable amount of clayey matter, and is evidently akin to loess, it is yellow in colour and may be 15 feet thick, perhaps more, for at a distance of some 1,500 yards from the water-hole the cutting does not cut through it. It has a rough vertical jointing, and is of such consistency that the perpendicular sides of the cutting do not fall in rapidly; they have stood uninjured in many parts for more than three years. There are irregular tubes of small diameter in the sand made by roots passing more or less vertically downwards. The sand is almost free from rock fragments at a distance of 10 feet or more from the shale floor,

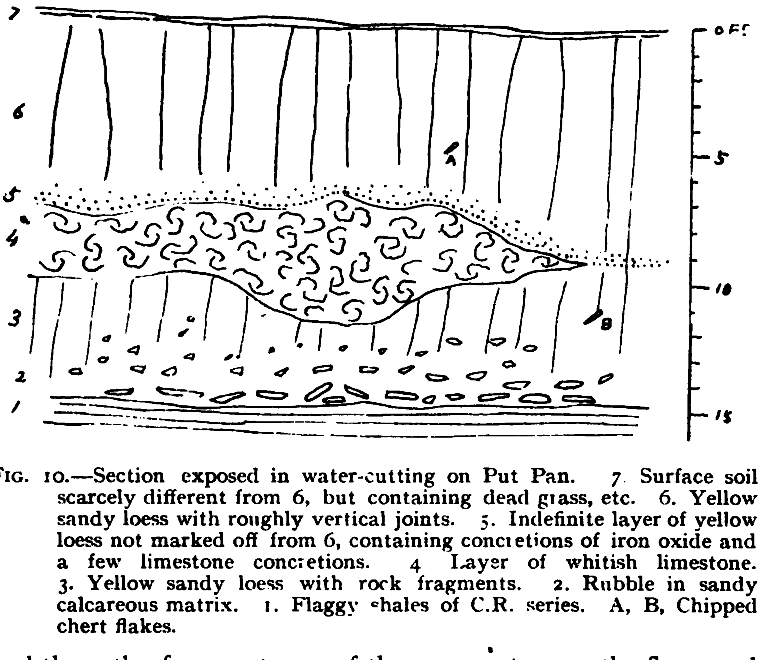

FIG. 10.—Section exposed in water-cutting on Put Pan. 7. Surface soil scarcely different from 6, but containing dead grass, etc. 6. Yellow sandy loess with roughly vertical joints. 5. Indefinite layer of yellow loess not marked off from 6, containing concretions of iron oxide and a few limestone concretions. 4. Layer of whitish limestone. 3. Yellow sandy loess with rock fragments. 2. Rubble in sandy calcareous matrix. 1. Flaggy shales of C.R. series. A, B, Chipped chert flakes.

and there the fragments are of the same nature as the floor, and they are angular. Two flakes of chert, just like those attributed to human workmanship and found in almost every part of the Colony, were seen in one part of the section, which was carefully examined—a part where a terrace has been cut half-way down, so that one can walk along the middle of the cutting. Near the upper surface of the limestone bands there is always a great number of balls and irregular concretions of brown oxide of iron; these are in the sand, not in the limestone, and they become fewer in numbers upwards. They form an irregular layer, which is continued for a few feet beyond the limestone where the latter thins out, as in Fig. 10. The sand does not contain shells

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of any kind, nor bones, so far as my observations went, and the same statement holds goods for the limestone. The limestone occurs in irregularly lenticular layers, and as it is so closely connected with the sand, it is convenient to describe it here instead of under the head of Surface-limestones. It may reach a thickness of 15 feet, but generally it is thinner, and where two layers exist, as in the place represented by Fig. 11, they are separated by a layer of loamy sand containing ferruginous concretions, just like the sand above the limestone. The surface of the limestone is very irregular. It is a whitish rock of variable consistency. Irregularly shaped masses are hard, and have

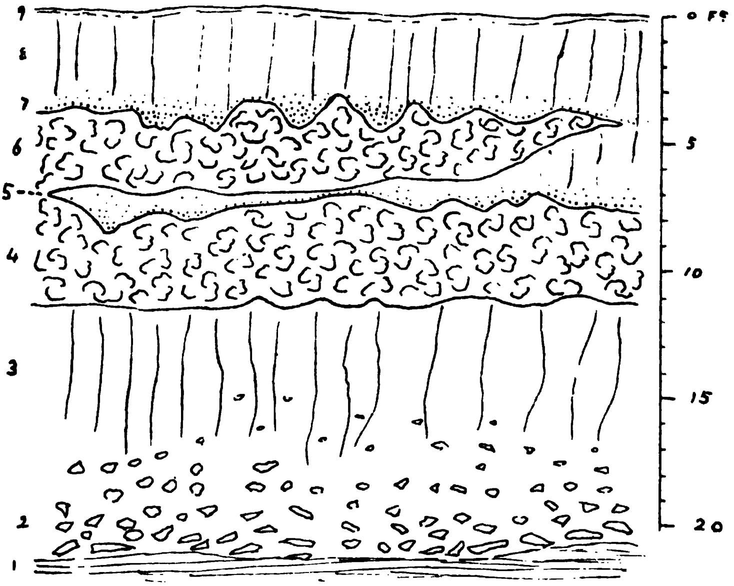

FIG. 11.—Section exposed in water cutting on Put Pan. 9. Surface soil. 8. Yellow sandy loess. 7. Yellow sandy loess with ironstone concretions. 6. Limestone. 5. Yellow sandy loess, with ironstone concretions. 4. Limestone, continuous with 6 on left. 3. Yellow sandy loess. 2. Rubble in sandy calcareous matrix. 1. Flaggy shales of C.R. series.

a concentric structure due to the presence of coats of slightly different tints following the form of the outer surface. These hard masses are embedded in rather softer limestone. The limestone contains sand grains and small angular fragments of shale; these are distributed as the similar fragments are in the sand, viz., they become more numerous downwards towards the rock floor. Immediately overlying the floor the rubble is a collection of angular shale fragments lying in a loose sandy limestone. In parts of the cutting the limestone approaches the surface rather closely, and at places in the veld not far off precisely similar

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limestone crops out; this rock differs in no way from the surface-limestone which appears in almost all parts of the Kaap and the Maremane anticline.

The Put Pan cutting gave me the impression that the limestone has been deposited within the sand, and that to a certain extent it pushes aside the constituents of the sand during its deposition. The materials thus pushed aside seem to be chiefly iron oxide and clay, and also much of the sand, but rock fragments larger than 1-10th of an inch or so, and many grains of sand very much smaller than these are included by the limestone.

Near the water-hole there is no limestone, and the sand there is much thinner than elsewhere. The cutting runs north-eastwards towards lower ground, and the surface deposits as a whole become thicker in that direction—in other words, they tend to level up the slope formed by the hard rock below. The limestone does not behave uniformly in the same fashion, its total thickness at any point is not necessarily greater than at another place nearer the water-hole, and it may be altogether absent.

Red sand is abundant on both sides of the Kuruman-Asbestos range; towards the Langeberg the sand becomes paler in colour. To a certain extent the distribution of the red sand is obviously connected with that of the ferruginous rocks of the Griqua Town series, but the Ongeluk beds (Middle Griqua Town) are very often accompanied by sand almost as deeply coloured as that on the Lower Griqua Town beds.

Near the Langebergen the valleys are usually found to be more or less deeply buried under sand, but its depth is difficult to ascertain. It wraps round the north end of the range, and the transverse valleys south of Olifants Hoek are so filled with sand that the mountains rise very steeply from an apparently flat plain from one to four miles wide without definite stream beds traversing them. In nearly all parts of the Langeberg the mountain side rises abruptly from a sandy plain, which abuts against the mountain so as to hide from sight the lowest 300 feet perhaps of the rock slope. This plain slopes very gently towards the nearest valley-line.

In the Koegas Field-Cornetcy there is much sand banked up against hills made of Griqua Town and Matsap beds. On Stink Water there is a ravine showing a section eight feet deep in the red sand; there is enough clay and iron oxide in the sand to give it strength to stand in vertical walls, which are due to a strongly marked jointing; it contains a few small pieces of rock, lava, and jaspers from the neighbouring Griqua Town beds. In the wide sandy country north-east of Piljaars Poort there are sand-hills which trend south-east, and are slightly concave to the north-east.

On the west side of the Langebergen the country is very sandy; the usual colour is yellowish or light red, but the re-

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markable sand hills of Witsands are almost white. These hills occur in an area about eight miles long and five wide; rocks of the Matsap group crop out at the summits of the highest hills and of some of the lower ones; the presence of the Matsap ridges is certainly an important factor in bringing about the accumulation of the sand, which rises to a height of from 100 to 200 feet above the surrounding country. The trend of the main sand hills within the group is N.N.W., and their steeper side is on the E.N.E. The two questions concerning Witsands that are difficult to answer are why the sand gathers in that spot, and why it is so white; the third question, the reason of the occurrence of water in several places, usually excites most interest and wonder, but, as will be pointed out presently, the presence of water is not very difficult to explain.

The accumulation of the sand round the Witsands kopjes has not been explained, and at present the local circumstances are not well enough known to allow the matter to be fairly discussed. The whiteness of the sand is due to the removal of the small amount of iron oxides which give the yellow and red tints to the sand of the surrounding country. In parts of the white sand area the removal of sand by wind has laid bare banks of cellular ironstone just like that found on the Cape Flats and many other parts of the Cape Colony; it differs from the ironstone of the Kuruman hills, etc., in being less compact and in containing no fragments of rock larger than sand grains. It seemed to me that the ferruginous colouring matter from the local sand has accumulated in this cellular ironstone, owing to the long continued action of the water which saturates the lower lying sand in the small area (8 by 5 miles) of Witsands. There were no clear sections which showed how thick the ironstone is or whether it occurs in beds within the sand or in a layer always near the bed-rock, but the exposures favour the view that it is in irregular layers within the sand and at a considerable height above the bed-rock, *i.e.*, that it occurs similarly to the layers of limestone in the Put Pan cutting. The outcrops are quite 18 inches thick, and loosened masses of that size lie near the outcrops.

An accurate survey of the area, combined with precise levelling, would be necessary to decide the cause of a constant supply of water within the sand area. The water is found at a depth of a few feet below the surface on flat places just within the outer groups of sand hills. People told me that it could be got anywhere near the hills, but I do not think that can be the case, for if it were the farmers who live there temporarily or permanently would not go to the trouble of fetching water from spots half a mile from their houses across very heavy sand. From enquiries made from people who have known Witsands for a long time I gathered that the level of the water rises regularly after rain and that it gradually sinks during the drought. After

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plentiful rains it stands above the surface in certain of the hollows. Though there seem to be always some hundreds of small stock watered daily at Witsands, as well as a small number of cattle, there never seems to have been a severe strain put upon the water supply. At the time of my visit (October, 1906) the water was 4 feet, 3 feet, and 2 feet below the surface at the three water-holes seen by me; it is fresh.

The quartzites of the Matsap series crop out at several places round the white sand area, and the intervals between the outcrops are covered with sand; the locality gave me the impression that there is either a rock basin or a rock valley dammed up by impervious surface deposits and filled with sand, which becomes saturated with water to a level depending upon the abundance of rain. The sand protects the water from evaporation to a certain extent, and hitherto this water has not been known to be exhausted during the severest drought. The rainfall of this district has not been recorded, but from the appearance of the veld during two rather dry years (1905 and '6), I think it is almost equal to that of the Kuruman district. It has been supposed that the Witsands water comes from a strong spring, but the fact that the water level rises and falls each season shows that some of the water has a more local source. If the underground contours of the sand were such that they would allow rain-water to drain away quickly the water would not rise above the low spots as it does. In several walks to and from the water-holes I could not decide whether they were at a higher or lower level than the flat ground outside; the paths lead over sandy rises and across low ground.

Witsands has long been known as a locality where "lightning-tubes" or "fulgurites" occur.[1] During my visit there I could not find one of them, nor were two natives sent to look for them more successful. I was told that they are got after heavy rain or strong winds, and that they stand more or less vertically out of the sand. Mr. Jooste, of Koodoos Kloof, Hay, kindly gave me three pieces of the tubes, which he had picked up at Witsands. They are rough glass tubes with walls 1-2 mm. thick, with a vitreous surface inside and a dull exterior covered with partly fused sand grains. The walls have collapsed in places, so that the tube is irregularly closed, and the outer side is ridged, owing to the folding in of the wall on each side of a ridge, like the wrinkles on a dried grape. The colour of the tubes is whitish grey. Fragments under the microscope show that the greater part of the wall is made of isotropic glass containing numerous air-bubbles. Partly melted sand grains (of quartz) are abundant. These fulgurites are evidently very like those described from various parts of the world.[1]

[1] R. Marloth, Trans. S.A. Phil. Soc. Minutes of Proceedings, vol. VIII. p. lxx.

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(2) *Surface-quartzites and ferruginous rocks.*

On the farms Roodemans Kloof and Paarde Kloof, which lie on the eastern slope of the Langebergen in Hay, there are large patches of a sandstone which passes into quartzites indistinguishable in hand-specimens from the surface-quartzites of the south of Cape Colony.

At Roodemans Kloof the rock forms an area about half a mile long and a quarter wide; it lies on a gentle easterly slope leading to the dry valley which traverses the farm from north to south. The rock is ferruginous in parts, consisting of grains of quartz embedded in a red and brown matrix. The exposed surfaces are often polished, and these portions are made of a very hard rock, consisting of quartz grains and small pieces of quartzite set in a dull siliceous matrix. A thin section of this rock (1660) seen under the microscope shews round and angular quartz grains set in a matrix composed of very small quartz individuals without crystalline boundaries; this quartz is not in crystalline continuity with the quartz grains enclosed by it.[2] No isotropic silica or other substance was seen in the slice. The transition from this very hard rock into a much softer variety, in which the place of the siliceous matrix is taken by earthy matter or by a ferruginous cement, can be seen in almost any part of the outcrops. Although the very hard rock is usually found at the exposed surface and the softer rock below it, the latter also occurs alone over areas of several square yards. These rocks are roughly divided up by vertical joints, and they pass out of sight under the sandy soil which forms the upper part of the slope. The greatest thickness of rock seen at Roodemans Kloof is only two feet; it passes downwards into sandy soil without a sharply defined limit.

On Paarde Kloof the surface-quartzite is exposed along the left side of the steep-banked valley leading south-eastwards from a large kloof in the Langebergen. Its upper surface slopes gradually eastwards and passes under gravelly soil a few yards back from the edge of the bank. It is evidently being cut back by the formation of the lateral valley, and a vertical thickness of 15 feet of the rock has been exposed in the process. The rock as a whole is rather earthy, a loosely consolidated sandstone with

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[1] For descriptions of these glass tubes see Charles Darwin's "Journal of Researches," etc., end of Ch. III. C. D. Gibb, The Geologist, 1859, p. 195, etc. P. Harting, Naturk. verh. d. Koningl. Akad. Deel. XIV. This last paper is illustrated, and the figures might almost have been drawn from Witsands tubes.

[2] This rock corresponds more closely with the "Eingekieselte" rocks of the Northern Kalahari (Botletle beds) described by Passarge and Kalkowski than with the other siliceous surface deposits of the same authors.

Passarge, Die Kalahari, 1904.

Kalkowski, Abh. der naturwiss. Gesellsch. "Isis" in Dresden. Jahrgang, 1901, pp. 55, etc.

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irregular tubes and holes filled with sandy earth; the tubes are from a tenth of an inch to one inch in width, and branch in the manner of plant roots. There are irregular layers and patches more or less deeply stained with iron oxides in the usual yellowish-white rock. Pebbles of quartzite and vein quartz, subangular and rounded, occur in thin layers and in small patches; they are usually embedded in a coarser grained matrix than the rest of the sandstone. The rock is not divided up into definite beds, though the occasional layers of gravel and ferruginous material lie nearly horizontally, and give the whole a roughly bedded appearance. At the exposed upper surfaces the sandstone passes into a very hard quartzite, as at Roodemans Kloof. A few yards back from the bank a pit has been sunk, apparently for prospecting purposes, ten feet into the sandstone; the rocks seen here are like those exposed on the bank.

Similar quartzites have not been noticed elsewhere in the district, but the more ferruginous parts of the Roodemans Kloof and Paarde Kloof rock appear to be of just the same nature as the rock formed by the cementation of gravel and soil by iron oxides in many localities in Hay and Kuruman, especially along the flanks of the hills made of the Lower Griqua Town beds.

In almost all the kloofs I examined on the flanks of the Kuruman-Asbestos range there are places where, owing to the removal of the sandy surface soil by water or wind, an irregular surface of hard cemented débris is exposed. This rock is made of angular, subangular, and rounded fragments of local rocks cemented together in a sandy ferruginous matrix. A similar material is often seen on the lower slopes of the hills between the kloofs. Where large fragments are few or altogether absent a hard ferruginous sandstone takes the place of the breccia or conglomerate. In positions such as stream beds where rounded water-worn pebbles usually occur, many of these are found in the matrix, together with angular pieces of rock, but on the lower slopes of the hills outside the kloofs the rock is a breccia.

This ferruginous breccia or conglomerate is especially well exposed near Daniel's Kuil, where it extends for a considerable distance from the hills over the flat ground of the Kaap Plateau; it must then lie on the limestones of the Campbell Rand series. It is seen to be covered by 12 or 18 inches of red sandy soil at the hole which gave to Daniel's Kuil its name (see p. 28). It here contains many pieces of black chert from the Campbell Rand beds, as well as fragments of the Griqua Town beds, and it is about three feet thick.

At Kuruman the ferruginous breccia is found in the village at a distance of five miles from the foot of the hills, and the same is the case at several localities between Kuruman and Griqua Town.

The rock occurs also in the wide valley cut out of the Griqua Town beds behind Khosis Reserve (called Gathlose Reserve in

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most of the maps), and at other places on the western side of the Kuruman-Asbestos range, but it does not appear to be so frequently developed on the west as on the east of those hills.

A quite similar rock is formed round all the hills made of the Blink Klip breccia on the Maremane anticline, but the included fragments are here pieces of this breccia.

The ironstone of Witsands has already been described (see p. 72).

Though these ferruginous rocks are probably only seen on the surface where the soil has been removed, there can be little doubt that they underlie the soil over wide areas in the neighbourhood of hills with much iron in them, and in the valleys within the hills, for they are met with in wells sunk in these places.

Although in the case of the Paarde Kloof occurrence the sandstone has been exposed by the cutting back of the valley bank, where the bed of the river is some 30 feet below the top of the bank, and the sandstone is therefore of considerable antiquity if its age be reckoned in years, these rocks, composed of whatever débris there happens to be at each locality, cemented together by iron oxides and silica, are doubtless in process of formation at the present time. The iron oxides and silica must have been taken out of ascending ground water charged with them, just as the carbonate of lime has been taken from such water to form banks of surface limestone, such as those described above from the Put Pan cutting.

There are masses of siliceous material associated with surface limestone in the tufa-covered ground between the Langebergen and the Kuruman hills, and again on England, a farm north of Geluk. These present important differences from the surface quartzites described above, and as but little is yet known about them, they will be briefly described in connection with the limestone in which they occur.

(3) *Gravels.*

Gravels are not developed to an important extent in any part of the district except between the Matsap ridge and the Langebergen, an area described in the last Annual Report (pp. 200, 201). It is possible that this gravel stretches much further than it has been seen, as it may lie under sandy soil north and south of the area mentioned. Some of the kloofs in the Langeberg have well-developed rock terraces, shelves cut by water, at a level of about 20 feet above the bottom of the present streams. On the farm Toto there are patches of gravel lying on such a terrace.

The most interesting gravels seen are those with a calcareous matrix at Mahura Muthla on the Kaap Plateau. Through some prospecting for diamonds they have been well exposed. They

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are exposed at a place which is slightly higher (a few feet) than the plateau to the east and west, and they lie some 10 feet above a pan with rocky bottom (of Campbell Rand limestone) immediately to the west. Their extent is unknown, and their mapping out would be a long and difficult work unless many new wells, etc., were being sunk. The exposures seen by me cover an area some 500 yards long by 50 wide, but in parts of it the exposures are small. The surface soil is reddish brown, and contains rough fragments of chert, a few agates, and artificial flakes of chert; this soil is about a foot thick, and is underlain by either a soft whitish limestone or a hard limestone with an irregular lumpy surface. If the limestone is hard it becomes softer below. The limestone contains well-worn small pebbles of agate, chert, and red jasper; at places these pebbles are very abundant, elsewhere they occur sparingly. At one place the depth of the soil and limestone is only 18-24 inches, and the underlying Campbell Rand limestone is exposed over an area of some 200 square yards, the soil and surface gravelly limestone having been stripped off by the prospectors. The blue dolomitic limestone is bedded horizontally, and presents a curiously pitted surface, owing to the presence of many irregularly circular depressions from one to two feet deep, evidently formed or at least enlarged by solution. In a different situation some of these depressions might have passed as potholes. In another part of the workings the bed-rock is reached at 8 feet, the overlying material being limestone, with round pebbles, very hard on the top and soft below. Another pit is down 12 feet in the pebbly limestone without exposing the bed-rock. Artificially chipped cherts occurs in the limestone near the surface, but I did not find these worked stones in such a position that they undoubtedly belonged to the gravel, and were contemporaneous with it. In addition to the small pebbles, there are larger rounded pieces of rock, including blue limestone from the Campbell Rand beds, chert from the same formation, grey and reddish quartzites that may have come from the Black Reef series, diabase from the Pniel group, and red jasper. Only one piece of rock which probably came from the Karroo beds was seen by me, a 3-inch pebble of silicified wood like that from the Ecca and Beaufort beds; Mr. Fenwick Stow, who was concerned in the prospecting, told me he had seen several of these during the washing of the gravel. In one part of the workings there is iron-stone gravel under the soil in place of the calcareous rock. In several places there are gravels with little or no limestone in the matrix lying below the usual limestone.

The agates, which form by far the greater number of pebbles in these gravels, are precisely like those in the river-diggings along the Vaal, and they doubtless came from the Pniel lavas. There is an inlier of these lavas near Takwanen, and they crop out round the edge of the plateau, usually at a lower level than

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the surface of the plateau, though on the north edge they probably lie in places above that level, *e.g.*, at Massouw's Kop, and in former times they may have done so over a wider area than now. In the Takwanen inlier, however, we have the levelled-off remains of a ridge partly made of the Pniel lavas, and it is quite possible that the agates came from this source, which is some 30 miles north-east of the gravel pits. Further work may reveal the presence of a nearer inlier. The source of the fossil wood cannot yet be decided; it is the only direct evidence yet found of the former presence of Karroo beds on the Kaap Plateau. No granite or schists were seen in the gravels, nor were any shells noticed in the limestone associated with them.

In the Langeberg region there is often a considerable depth of coarse rubble in the kloofs quite near their steeply-graded tract. Where the kloofs are very steep the solid rocks crop out all the way along the bed, but where the grade becomes less, though before one reaches the almost flat ground, there is much rubble, made of angular fragments of the Matsap quartzite and sand. At Mount Temple there is a water cutting about 30 feet deep; the uppermost 20 feet of material is coarse rubble, in which the blocks are as much as 15 inches across; below this there is sandy débris, with very little clay in it. The cutting does not reach the solid rock.

Similar sections, though without such a definite lower layer of sand without rubble, were seen at several farms along the eastern side of the range.

(4) *Limestones and associated siliceous rocks.*

The surface-limestones can be roughly divided into two classes, those which occur in patches, either at intervals or so thickly that they almost form wide connected areas, and those in large areas, either narrow and occupying the floors of valleys or of great extent.

The first class of limestone is found overlying rock containing carbonate of lime or lime-silicates, which produce carbonate of lime on weathering. The chief rock formation on which this kind of surface-limestone is formed in this district is, of course, the Campbell Rand series. Almost everywhere on the Kaap Plateau and the Maremane anticline patches of surface-limestone are seen separating the rough outcrops of the underlying formation or covering it entirely. In the sandy country a layer of tufaceous limestone is usually found in a well or other cutting through the sand. The depth below the surface of the sand at which the limestone is first seen varies in the exposures I saw up to 10 feet, and the thickness of the calc-tufa varies indefinitely. Under the sand on the Kathu Reserve it is more than 15 feet thick, but the underlying rock is not exposed there, and

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its nature is therefore uncertain, though it probably belongs to the Campbell Rand group. The limestone is very hard, as a rule, at the surface and to a depth of two or three inches from it, but further from the surface it is generally softer. It includes sand, pebbles, and any earthy matter that may happen to be present. At Mahura Muthla on the Kaap there is a gravel cemented together with white limestone. The pebbles in this case are of agate, and other rocks which do not occur in the immdiate neighbourhood, and the gravels have been prospected for diamonds. The exposures thus made show that the thickness of the limestone varies up to twelve feet within 100 yards, and that in places it is hard throughout. It may rest directly on the Campbell Rand limestone or a bed of loose gravel may lie between the two limestones. These surface-limestones were formed by the deposition of lime from water which evaporated at or near the surface. The water doubtless got the lime from the underlying rock. In places where a continuous supply of water is maintained, as in spots which are always damp, owing to the presence of a weak spring, the deposit of limestone takes place rapidly. A remarkable instance of this was shown me by Mr. Cawood, of Orange Grove (below the escarpment and between Baviaans Krantz and Schmidt's Drift). He opened up a damp spot and found the drill and pick marks, made by the first owner of the farm some 27 years previously, at a depth of 3 feet below the surface of the tufa. This is probably an extreme case, but similar deposition must be in progress at many places along the escarpment where water is constantly oozing from the rock. In an open flat, such as the Kaap Plateau, the deposition is brought about by the ascending water after rain has saturated the ground and when the latter dries out. A description of the limestone exposed in the Put Pan water cutting is given on p. 68, and it is probably typical of a very wide area.

The shape of the limestone masses may be very irregular. Near Gamopedi, on the left bank of the Kuruman River, the limestone occasionally projects above the red sand flanking the Kuruman hills. At one spot large masses of this rock had been taken out from a pit, which, however, is now mostly filled with sand, so that the rock *in situ* is not well exposed. The loose blocks show that the limestone may be two feet thick, and some of it has a curious appearance, owing to the presence of more or less tubular holes up to two inches in diameter going through the rock in various directions. These are filled with red sand, except near the surfaces, where the sand can fall out, and by the gradual growth of the limestone small pockets of sand must be completely enclosed; by the deposition of limestone in these enclosures there will be produced a patch of very sandy limestone, just like certain sandy lumps sometimes seen in the limestone. Otherwise the deposition of the lime appears to force aside a considerable amount of sand, and only to include a small

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part of that which once occupied the space now filled chiefly with limestone.

Though surface-limestone is more abundant on the dolomite areas than elsewhere, it is not confined to them. The Lower Griqua Town beds have very little limestone on them where they are not in the neighbourhood of a valley draining a dolomite country. The Matsap Flats, for instance, are covered with much limestone lying on the Lower Griqua Town beds, but an old valley bottom draining the southern part of the Maremane anticline traverses the plain on its western side, and the rest of the plain has probably at times been crossed by the old river; so formerly, even if it is not the case at present, the subsoil must have been saturated with water containing carbonate of lime in solution. Following the Lower Griqua Town beds southwards towards the Stink Water boundary, we find very little limestone either exposed at the surface or in wells. Near the top of the Lower Griqua Town beds, however, calcareous rocks are again found, though the carbonates are present in comparatively small quantities, and in places surface-limestone of local origin again appears. Such is the case at Dunmore, south of the great Ongeluk-Witwater syncline, where 15 feet of loose white limestone have been exposed in a pit.

On the Ongeluk volcanic rocks (Middle Griqua Town) surface-limestone is in places developed in considerable quantity, especially where the ground is flat, as in the northern part of the Ongeluk-Witwater syncline. The lavas very probably yield enough lime on weathering to account for the surface-limestone seen.

No limestone worth mentioning has been found on the Upper Griqua Town beds south of the Bechuanaland fence, nor on the Matsap beds, except where they are traversed by valleys coming from a limestone area, such as the Matsap "loop" south of Bakens Kop. The Upper Griqua Town beds contain a few thin beds of dolomitic limestone, but no calcareous rocks have been noticed in the Matsap beds, excepting some of the lavas which contain calcite as an alteration product. These lavas do not cover a wide area at the surface, and they either form hilly ground unfavourable for the accumulation of limestone or are deeply buried under sand.

The second class of superficial calcareous rocks, those which cover a wide area continuously, are very probably closely connected with certain of the first class, but their separation is not convenient until more is known about them.

The tufa which fills or nearly fills old valleys draining dolomite areas requires no special explanation. It was referred to in the last Annual Report in connection with the Matsap valley. The valley which drains the northern part of the Maremane anticline is also largely filled with tufa down to its junction with the

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Kuruman River below Tsenin. No outcrops of the underlying rock were seen below Gamagara, and the country on the right bank is covered with sand, through which surface-limestone crops out over a very large area. In a traverse from the north end of the Langeberg to Gamopedi, on a line sixty miles long, the underlying rock was only found once, on Alister, till the foot-hills of the Kuruman range were reached. A large part of this wide area is covered with surface-limestone, though it is very improbable that the Campbell Rand series directly underlies the superficial deposit. It is difficult to decide how much of this limestone is derived from the water coming down the valley, but it seems to me at present not unlikely that the whole of it was so derived. The area is flat, and but slightly above the valley floor (at most 100 feet). On the farm Flatlands, east of the valley bottom, there are two wells being sunk in the limestone, 50 feet and 40 feet deep respectively. In neither case has the bedrock been struck. The material thrown from these wells is interesting, though, as at the time of my visit there was no one there, I could not go down to see the section, and consequently I am ignorant of the depth from which certain rocks came. There is softer rock at the surface and within two or three feet of it than that which comes from greater depths. A band of limestone with subangular fragments of banded jaspers and volcanic rocks, all from the Griqua Town beds, was passed through in the western of the two wells, but at what depth I do not know. A red earthy rock occurs with the limestone, and is similar to the red material thrown out from wells between the valley and the Langeberg; it contains small crystals of calcite. The most interesting fact about the limestones on Flatlands is the occurrence of opaline silica and chalcedony in irregularly disposed veins and cavities in the limestone, and also as a cement in masses with irregular shape. Parts of the siliceous material are as clear as glass, and are quite isotropic; this material seems to be the same as hyalite. Other parts, also isotropic, have a delicate blue colour. The bulk of the silica, however, seems to be in the form of chalcedony, for it is doubly refractive, and shows the usual appearance of agate under the miscroscope. Thin sections of these rocks have not yet been cut, but the siliceous portions were examined in the form of powder and chips.

No shells of molluscs or other organic remains have been found in the limestone, but one mass of opaline silica looks as if it might have been formed in the place of a shell such as *Unio*, but this is uncertain.

On the farm England, about eight miles north of Geluk, and lying at the head of the Mashowing valley, there is a considerable amount of surface-limestone overlying granite and gneiss. In one well it is 15 feet thick. From the well at Mr. Cullinan's garden there comes a siliceous rock forming irregular flattish masses in the limestone; this rock is like some of those men-

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tioned above from Flatlands. From a hole some half-mile from Mr. Cullinan's house there were thrown large masses of siliceous rock, brittle as glass, in which no recognisable detrital fragments are seen. It is made of opaline silica and chalcedony. Its relations to the sand at the surface are not well exposed, though it appeared to lie under about three feet of reddish sand. Some masses of ironstone, made of hydrated iron oxide and rock fragments and containing chips of the opaline rock, occur, overlain by sand, in the immediate neighbourhood.

Calcareous tufa is not abundant in the Mashowing valley near Motiton. An occurrence at the Klein Chwaing pan will be mentioned later.

X. Pans.

The variously shaped shallow depressions called pans are rather numerous in the district under consideration. They vary in size from a few yards to more than a mile in diameter. In shape they are usually circular, but many oval and a few quite irregularly shaped pans have been seen. Many of them are probably hollows in the solid rock, perhaps only a few feet—less than ten—deep, but this fact is not easy to prove, for there is always some sandy or tufaceous material round the pan, and there are not often sufficient exposures of rock to prove its continuity at a higher level than the floor all round the pan.

It will be convenient to describe briefly one or more pans from each formation on which they lie.

On the granite area only one pan of any importance was seen; it is on the farm Zoutpan, and quite close to Klein Chwaing Reserve, which takes its name from the pan. Though the farm is called Zoutpan, I was told that salt is not collected from the pan; the surface is brak and the water, when present, is too brak for animals to drink, but the salt is not in large enough quantities to collect. The pan is nearly circular and about 1,000 yards in diameter; formerly it was wider in the north-south direction, for there is a flat grassy surface about 800 yards long directly south of the pan a few inches above the surface of the pan itself. The floor of the pan generally is a grey gritty and sandy mud, with salt crystals and some gypsum in it. There are four outcrops of gneissose granite in the pan rising about two feet above its surface. To the north there is a grassy slope rising to a height of about 100 feet above the pan; the soil is sandy, with some tufaceous limestone, and the nearest granite seen is about a mile away. To the east the granite is exposed in water-holes; it lies under a grey soil and loose earthy limestone. The granite in these holes lies some 20 feet or more above the pan. To the west similar sections are seen, and that represented in Fig. 12 was taken from one of the western water-holes. The soft limestone is earthy, and contains shells of

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Physa; it is traversed by more or less vertical tubular holes. The gneiss at the base of the section lies some 15 feet above the pan floor. Towards the south the ground rises gradually from the grassy flat south of the pan, and at a dry well about three miles to the south granite is seen in places considerably above the level of the pan. There are small ridges of yellow blown sand round the south end of the pan. The water from the holes east and west of the pan is fresh.

The few other pans seen on the granite north-north-east of Klein Chwaing are under 100 yards in diameter, and are bare places where the granite is exposed at the surface; they are less than 10 feet below the surrounding ground, which has a sandy soil derived from the granite.

No pans were seen on the small ridge made by the Kraaipan formation on Kameel Rand and Hamburg.

A pan on the Pniel lavas lies just south of the Kraaipan ridge.

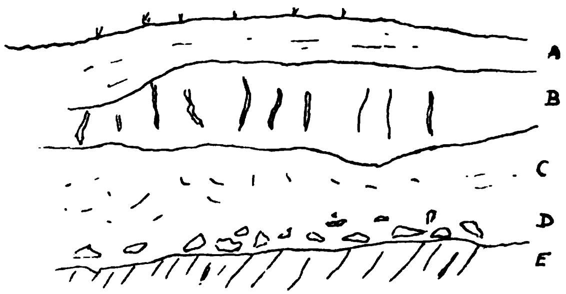

FIG. 12.—Section in water hole on the west side of the Klein Chwaing Pan. A, Soil with fragments of limestone and quartz. B, 18 to 24 inches of loose limestone with Physa shells. C. About 18 inches of loose soil and limestone. D, Rubble of gneiss fragments. E, Gneiss.

It is under 200 yards in diameter; the soil is a thin grey-brown mud and there are numerous outcrops of the lavas on the pan floor. The surrounding ground is a red sandy soil on the north towards the Kraaipan formation and a grey soil on the other sides, underlain presumably by lava. There is a large ill-defined grassy pan on Morgenzon lying on the lavas which make a few outcrops where a road has cut through the thin soil. Another pan on the same formation is found on Schiet Fontein, also with a few outcrops of amygdaloid. Small pans, in all of which the rock is exposed at places, were seen on the blue lavas of England and Harbro. On Kaffir Pan the only pan seen lies on the acid lavas of the Zoetlief beds, exposed in low rounded surfaces on the floor. A small pan lies on the Black Reef beds of Schildpad Kuil; the soil is thin, but the Black Reef beds do not crop out on the floor. The large pan on Mooi Fontein lies on the boundary between the Black Reef and Campbell Rand series; the former is seen in a cutting on the north margin of the pan,

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and crops out in a few places near that edge; the limestones of the Campbell Rand group crop out on the western extension of the pan, which is elongated in the direction of the strike of the beds. Another pan in a similar position was seen on New York. Towards Geluk there are several ill-defined pans on the same horizon. Most of these are grass-covered, but the Mooi Fontein pan has a brak calcareous mud floor.

By far the greater number of pans seen lay on the Campbell Rand limestone of the Kaap Plateau and the Maremane anticline. In many cases these are more or less circular patches, in which the limestone crops out abundantly, usually with more or less hard tufa lying between and partly covering the outcrops. They are only a few feet below the country round them. The large Rooi Pan near Daniels Kuil is a wide grassy depression in the upper part of the dry river which traverses the Plateau south-east of Daniel's Kuil. On A 58 a well has been sunk just outside the depression through 20 feet of loose calcareous rock, a surface-limestone. The top of the well is about 15 feet above the floor of the depression. The Rooi Pan is only a wide valley partially filled in with calcareous tufa and sand. Parts of it are rather lower than others, owing to the irregular accumulation of the surface deposits, and after heavy rain water stands for a few hours in various places.

Between Kuruman and Taungs several pans with white calc-tufa on their floors were seen. Uusually the tufaceous limestone is rather soft, but in some cases the surface is hard in irregular patches, and the softer material lies between the hard outcrops.

On the area occupied by the Griqua Town series pans are not very abundant. Those on the Lower group are always small. The Middle group (Ongeluk lavas) has more pans on it; on the north end of the Ongeluk-Witwater syncline, where there are wide flats on the lavas or on diabasic rocks intruded amongst those lavas, there are many wide pans covered with grass, especially on Vogelstruis Fontein and between that farm and Groen Water. Several shallow prospecting pits were sunk on that area during 1906, and they all showed calcareous tufa overlying decomposed diabasic rock. West of the Kuruman hills there are pans on the Ongeluk lavas, and many were seen on the same group in the country between the Paling fault and the Langebergen. In these pans the underlying rock was never seen in outcrops, though wells in some cases showed that it lies near the surface. The floor of these pans is either a sandy mud or tufa with a considerable amount of clayey matter in it. The Ongeluk lavas and the intrusive rocks associated with them appear to decompose more uniformly in such situations than the granite, Pniel and Zoetlief lavas, and the Campbell Rand beds. The pans on the Ongeluk beds west of the Paling fault and near the Kuruman hills are evidently slight hollows in the solid rock,

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for the lavas crop out near them on all sides. There are but few pans on the area occupied by the Matsap series, and those that do occur are in valleys between rather high ridges, where there is a considerable accumulation of surface deposits. In one such pan east of Dunmurray a well has been sunk through some ten feet of sandy material into quartzites. No quartzite outcrops were seen in any of these pans, which are small and of slight depth.

In the large tracts of country on the Kaap Plateau covered with thick reddish sand pans are rarely seen, and the same is the case in the surface-limestone area south and east of the Gamagara valley; in one small pan seen in the latter area and referred to on a previous page a well has been sunk 40 feet into the limestone without exposing the underlying rock.

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GEOLOGICAL SURVEY

OF THE

EASTERN PORTION OF GRIQUALAND WEST.

BY

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GEOLOGICAL SURVEY
OF THE
EASTERN PORTION OF GRIQUALAND WEST.

By ALEX. L. Du TOIT.

Introductory.

The area mapped extends from a point a little north of Taungs as far southwards as the Orange River, and is bounded on the east by the Transvaal and the Orange River Colony, and on the west by the Kaap Plateau. It covers an area of a little over 6,000 square miles, and includes the whole of the Division of Kimberley, the greater part of Herbert and Barkly West, and the southern portion of Vryburg.

Topographical Features.—The channel of the Orange River is shallow in depth at Hopetown, but rapidly deepens, until the river is hemmed in by walls of diabase, several hundred feet in height. From a point a little above Mark's Drift to its confluence with the Vaal River, the gradient is flatter, and the banks are low and sandy. The country along the Vaal is more diversified, there being high ridges at Douglas and to the north of Schmidt's Drift.

The Harts River winds about in a broad shallow valley, and has an extremely low gradient. To the west a gentle slope, broken by occasional ridges, leads up to the base of the escarpment of the Kaap Plateau.

The altitude of the edge of the escarpment does not vary appreciably from 4,000 feet above sea-level between Vryburg and Campbell; from the edge the plateau rises gently, but continuously towards the north-west.

To the east of Taungs there is a similar plateau, with almost the same altitude. This is continued southwards as a gentle ridge, and forms the watershed between the Harts and Vaal Rivers. A most unique feature about the Harts River is that in its upper reaches its channel is several hundred feet below the bed of the Vaal at Warrenton. Such a case, in which a tributary stream flows for some distance at a lower level than the main stream, is most unusual.

The eastern portion of this area consists of broad sandy flats, dotted with flat-topped dolerite-capped hills. The highest point is Kols Kop, near Enslin Siding (4,486 feet).

The Geological Formations.—With the exception of brief notes upon the geology in the neighbourhood of Kimberley and the "Diggings" by Chaper, Cohen, Moulle, Bauer, Stow, De Launay, Gardner Williams, and Coe, and excluding the description of the Diamond pipes, the only detailed account of any

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part of this area is that by G. W. Stow,* dealing with a strip of country extending from the Modder River to Douglas and Campbell.

A report by Stow describing the area between Kimberley and Douglas remains in manuscript in the library of the Geological Society at Johannesburg. To this I have had no access however.

Stow's paper suffers from the mass of insignificant detail with which it is overburdened; moreover, he confounded the Karroo dolerites with the Pniel lavas, and imagined that there was a definite and regularly ascending succession of Karroo strata from west to east. He does not seem to have completely understood the nature of the Dwyka conglomerate and boulder-shales, or realised the rapid variation in character and altitude which they show. Since he gave the first connected account of the geology of Griqualand West, several of Stow's names have been retained. It would be well if the term "Backhouse conglomerate," however, dropped out of use.

The geological formations may be arranged as below, in descending order:—

Karroo System.	Ecca series:—shales.
	Dwyka series:—"white band," upper shales, boulder-beds.
Transvaal System.	Campbell Rand series:—dolomites, limestones, cherts, and shales.
	Black Reef series:—quartzites and flagstones.
Ventersdorp System.	Pniel series:—volcanics, quartzites, and conglomerates.
	Zoetlief series:—rhyolites and conglomerates.
	Granite and gneiss.

The wavy line indicates an unconformity.

In addition, we have numerous basic intrusions, both of pre- and post-Karroo age, the extremely numerous kimberlite (blue ground) pipes and fissures, and the superficial deposits, including the diamondiferous gravels of the Vaal River.

The diamond-bearing formations will be treated of separately in Sections II. and III.

I must here take the opportunity of acknowledging the assistance which I have been afforded by the Manager of the De Beers Company and the various officials connected with that Institution, among whom Mr. Addams, Chief Mine Surveyor, must be specially mentioned. To the managers of the outside mines, I am also indebted both for information and for specimens.

* G. W. Stow. Quart. Journ. Geol. Soc. Vol. XXX, p. 581, 1873.

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SECTION I.—GENERAL GEOLOGY.

I. THE GRANITE.

Although there can be but little doubt that the granite extends continuously below ground from the division of Mafeking into that of Prieska, there are only a few places, and these some distance apart, where the overlying formations have been sufficiently denuded away to reveal it.

In addition, we have the sections afforded by the De Beers Mine, where the granite has been penetrated by the main shaft at a depth of 2,136 feet, and by the Kimberley Mine, where it has been struck at 2,702 feet, and proved to the depth of nearly 3,000 feet below the surface.

On Modimoe, nine miles to the north-east of Taungs, a gentle anticline, striking north and south, and pitching towards the Harts River, brings up the granite from below the diabase. The rock is a grey or slightly pinkish medium-grained muscovite granite, possessing in places a feebly-developed foliation. It is traversed by a few pegmatites and by quartz veins.

Nowhere else is this formation seen in the district of Taungs, but Dr. E. Jorissen informs me that an inlier of granite occurs on Fourie's Graf (Transvaal), in the Pudimoe valley, a little to the north-west of Modimoe. Further up the Harts River, in Bloemhof,* granite covers a wide area.

The granite in the De Beers Mine is a well-foliated, hornblendic variety, practically a gneiss, with foliation planes striking about north and south. The rock is seamed in all directions by veins of pegmatite, carrying pink felspar and either muscovite or biotite mica. Another variety of granite from the mine carries instead of hornblende a little greenish biotite, which is intergrown with epidote, the latter being a primary constituent. The rock in the Kimberley Mine is a grey biotite-gneiss.

The next occurrence of granite is on the left bank of the Riet River, at a point about a mile and a half from the Orange River Colony boundary; the outcrops only cover a small area. The granite is, as a rule, a fine-grained gneissic variety, containing biotite-mica, and having narrow aplitic bands. The foliation planes strike north-westwards.

By the denudation of an anticline in the Ventersdorp system on the north bank of the Orange River between Douglas and Hopetown, a core of granite has been revealed. Outcrops are infrequent, owing to the amount of Dwyka in the valley, as well as to the thick sandy soil.

* G. G. Holmes, The Geology of the South-Western Transvaal. Trans. Geol. Soc. S. A., Vol. IX, p. 95, 1906.

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On the farm Ettrick and close to the homestead is a patch of medium-grained foliated biotite granite, sometimes carrying muscovite mica in addition. The foliation planes strike north-north-eastwards. To the south are two little hummocks of granite, surrounded by Dwyka conglomerate.

On the north side of Summerhill granite appears below the Pniel quartzites, the latter dipping towards the east at a low angle.

The rock is a highly-foliated muscovite gneiss, with both fine and coarse grained bands, traversed by quartz veins. The foliation planes strike about north and south.

The last granite outcrop, and the most remarkable for several reasons, forms a small mound on the farm Donnybrook, a little to the east of the railway at a point several miles north of the Orange River. It is about 50 yards long by 30 broad, and rises from a flat of Dwyka shales. Although the shales abut directly against the granite without any glacial conglomerate intervening, there can be no doubt that the mass is a glaciated hummock, while it is the furthermost exposure yet known of the old Karroo floor up the valley of the Orange River. An odd feature in connection with this little dome-shaped mass of granite is the fact that a thin sheet of Karroo dolerite has been intruded along the junction with the overlying shales, and has also severed the crown of the dome from the rest of the mass. A little prospecting shaft shows, beginning from the bottom, two feet of coarse dolerite, with a tachylitic fine-grained selvage at the junction with the granite. The latter is three feet thick, with foliation planes dipping at a very high angle. Above comes the base of another sheet of dolerite, and for a distance of about a foot there is a transition zone between the acid and the basic rock. The surface of the granite exposure has numerous little patches of dolerite adhering to it or penetrating between the joints.

Wherever the granite is fresh and hard, the junction with the dolerite is either sharp or the transition takes place within a distance of about half an inch. Along the original surface of the hummock, where the rock had been weathered and shattered during its glaciation in Dwyka times, there has been a great amount of incorporation, producing a belt of brownish grey coloured rock up to eighteen inches in thickness. The basic magma has permeated the friable granite and partly dissolved the fragments, producing a mixed rock, which is frequently brecciated, and has a kind of gneissic structure.

The granite is a fine-grained, light-coloured variety, with foliation planes striking north-north-east. Here and there it is somewhat porphyritic.

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II. THE VENTERSDORP SYSTEM.

In the area to the north, described in last year's Report, this formation was divided into a lower and an upper group, separated from one another by an unconformity. To the lower one, consisting mainly of acid volcanics, the term Zoetlief Beds was given, while the upper one, composed of basic lavas and breccias, quartzites, and conglomerates, was termed simply the Diabase Formation.

Both divisions occur in the area now described, and the latter group is seen to correspond to the *Pniel Volcanic series* of Stow.*

A. The Zoetlief Beds.

The quartz-porphyries (rhyolites) proved in the workings of the Kimberley and De Beers Mines and cropping out on the Riet River correspond to the Zoetlief beds of the Vryburg Division. The succession at Kimberley is so closely paralleled by that on the Riet River that it will be well to commence with the description of the latter area.

As shown on the map (Fig. 1), the rhyolites occur west of the railway, in a series of detached outcrops extending from Klokfontein Siding across the Riet River. The majority of these are little hummocks surrounded by the Dwyka formation, a proof of the very uneven floor upon which the latter rests. The Klokfontein rhyolite was observed by Stow,† but was mistaken by him for a quartzite.

The rhyolites have rather constant lithological characters; they are lavas with a stony base in which are set small blebs of quartz, while phenocrysts of orthoclase felspar are not prominent. Boulders of this material when occurring in the Dwyka conglomerate to the south-west can without hesitation be distinguished from the numerous quartz-porphyry erratics from other sources. A most striking feature of the rhyolites is the fine fluxion structure which they exhibit. On Witkop Laagte the planes of flow dip evenly at an angle of about 20° towards the south-west, but in all other outcrops the structures become complex and the fluxion-planes are contorted, sharply folded, and often knotted. Surfaces of sliding are numerous, showing parallel striping and grooving owing to the presence in the moving material during its plastic condition of hard quartz blebs. Some of the lavas have such a well-developed fissility that they can be cleaved to form flagstones.

That the structures described are not due to earth-movement is shown by the absence, as a rule, of any constancy of dip or strike even for a few yards.

* G. W. Stow, Quart. Journ. Geol. Soc., Vol. XXX, p. 581, plate 35, 1873.
† *Loc. cit.* p. 584.

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Brecciated rock occurs only now and then; one outcrop was observed along the railway at $619\frac{3}{4}$ miles, where the rhyolites pass into a marvellously tough fine-grained breccia. The exposure is entirely surrounded by dolerite. Amygdaloidal and compact varieties are scarcely represented.

Relation to the Pniel Series.—The relation to the granite inlier on Klipdrift is not seen, but the contacts with the overlying diabases are exposed at several points. Along the Riet River

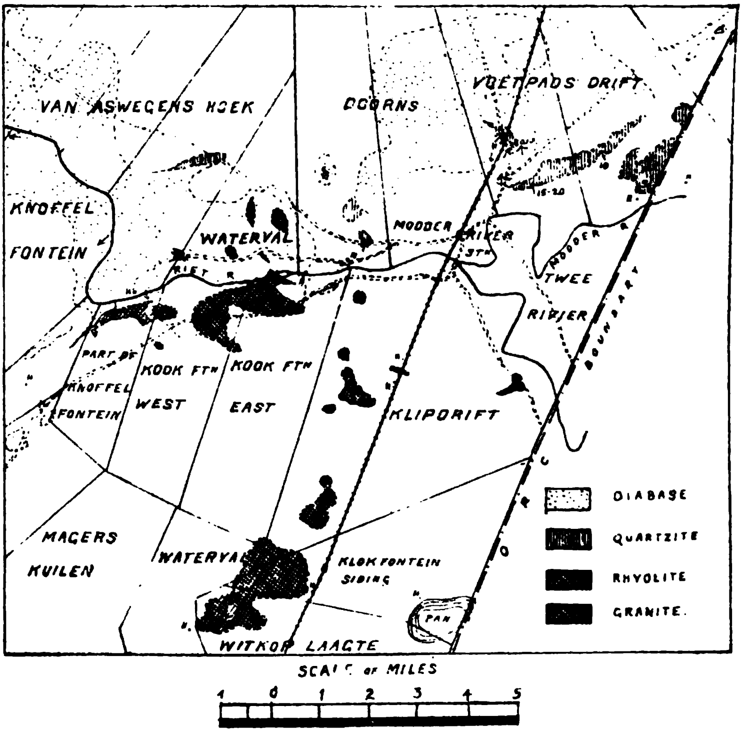

FIG. 1.—Geological Map of the area at the junction of the Modder and Riet Rivers. The unshaded portions are occupied by Karroo and recent deposits.

and to the north the rhyolites form low hummocks surrounded by diabase. Their position precludes the possibility of their being inliers due to folding only, inasmuch as the overlying diabases have low dips.

The uncomfortable nature of the junction is further borne out by the fine sections in the gorge of the Riet River at the south-eastern corner of Waterval. The surface of the rhyolite forms abrupt ridges and hollows, over which the diabase has flowed, the inclination of the contacts being as high as 45°. The banding in the rhyolite due to fluxion is nearly parallel to the ridges

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(west-north-west), and more or less vertical, and has doubtless been a factor in their formation. Different beds of diabase are brought in turn into contact with the vertically banded lavas, and the material at the contact often contains angular fragments of rhyolite.

That the rhyolite extends below the diabase in a northerly direction for some distance, perhaps continuously to Kimberley, is indicated by the presence of boulders of that rock as inclusions in the "yellow-ground" of a pipe at Wimbledon Station. These inclusions differ lithologically from the quartz-porphyry so abundant in the Dwyka conglomerate, and cannot, therefore, have been derived from that formation.

Kimberley Area.—In the De Beers mine the granite has been proved at a depth of about 1,900 feet in a winze close to the edge of the pipe (Fig 2). From this point the granite-rhyolite junction falls towards the north-west and dips below the 2,040-foot level a short distance from the main shaft. The granite surface then becomes steeply inclined, and though the base of the rhyolites is reached in the shaft at 2,075 feet, the granite is only cut at the depth of 2,137 feet, the intervening strata consisting of coarse green quartzites and a basal conglomerate several feet in thickness.

The sedimentary rocks are not seen in the 2,040 level, and the whole formation must abut unconformably and thin out against a slope of granite. From the De Beers mine the beds slope towards the Kimberley mine, and increase in thickness. The 61 feet of sediments have thickened to 106 feet at the edge of the Kimberley mine. From this point they continue to slope towards the main shaft, and then become nearly horizontal. The section in the shaft is as follows:—Quartzites, 62 feet; rhyolite, 141 feet; quartzites and flagstones, 110 feet; and conglomerates, 106 feet. Since the flow of rhyolite is absent both in De Beers and at the edge of the Kimberley mine, it must thin out and disappear within a distance of a quarter of a mile, and must therefore be a wedge-shaped intercalation.

The flagstones are very micaceous and fissile, and are finely ripple-marked; the quartzite is a hard, gritty, green variety, which contains pebbles and passes into a conglomerate. The inclusions are well rounded, and may attain a diameter of a foot. They consist of quartz, white or pale-greenish quartzites, striped quartzite, and granite and gneiss, chiefly muscovite varieties. The matrix is a green quartzite, containing a certain amount of carbonate in veins and patches; it is intensely hard, and it is impossible to obtain unbroken pebbles from it. The base of the conglomerate has been reached at the depth of 2,702 feet in No. 9 Prospect Shaft, so it is clear that the granite surface must have a considerable inclination between the two mines.

In the Eighteenth Annual Report of the De Beers Consolidated Mines (1906), from which I have obtained much informa-

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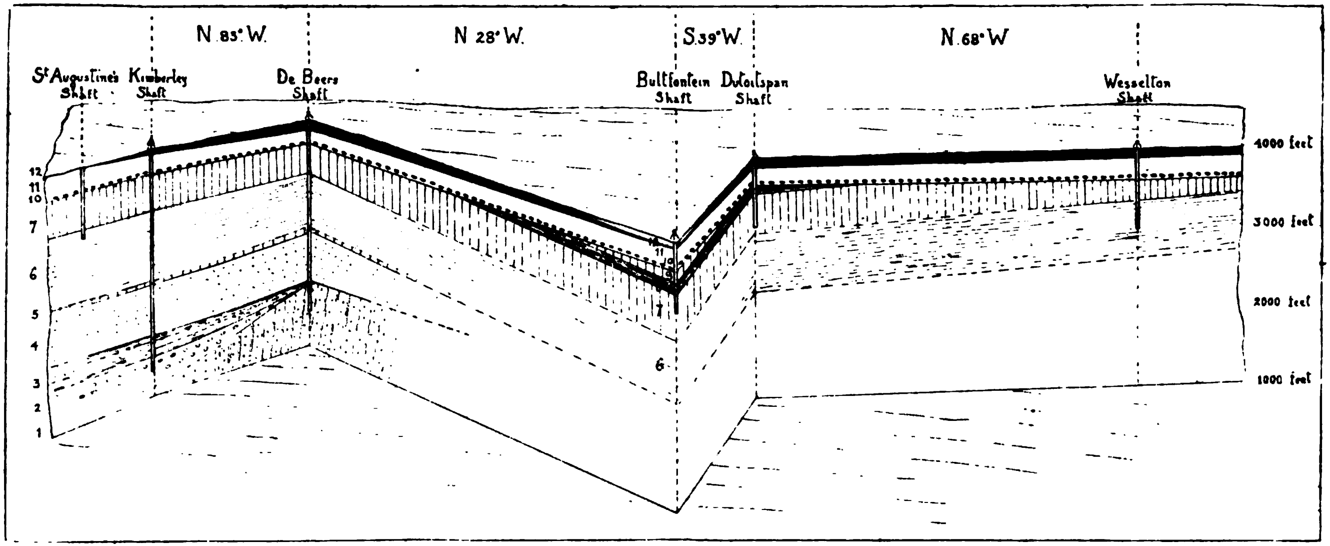

FIG. 2.—Sectional elevation through the Kimberley group of mines, taken from the south. 1, gneissic granite; 2, conglomerate; 3, quartzites with an interbedded rhyolite flow; 4, rhyolite (quartz-porphyry); 5, diabase; 6, quartzites; 7, diabase and amygdaloid; 8, quartzites; 9, diabase; 10, Dwyka conglomerate; 11, Dwyka shales; 12, dolerite.

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tion, the conglomerate has been called the Vaal River Conglomerate, since it is regarded as the lowest member of the Vaal River or Ventersdorp system. The naming is not a matter of much importance, but I think that the term Kimberley Conglomerate may perhaps be preferable.

The sedimentaries underlying and intercalated with the rhyolites have, as their composition indicates, been derived by the denudation of an area of granite and quartzite. This probably lay somewhere toward the east.

The thickness of the volcanic rocks is 762 feet in the Kimberley main shaft, and 868 feet at the edge of the pipe; the total thickness of the whole formation must exceed 1,300 feet.

The volcanic rock consists mainly of a massive pale-green quartz-porphyry or rhyolite. Amygdaloidal and felsitic varieties are also present, and there is every transition from compact to highly amygdaloidal or pumiceous types, while acid brecciated lavas and tuffs are also, though not abundantly, represented. Vesicular varieties are more abundant toward the upper limit of the volcanics—for example, in De Beers Mine, between 1,440 and 1,500 feet.

A petrographical description of some of these rocks has been given by Mr. Rastall,* and to this there is little to add. Thin slices of the rhyolites prove them to be almost identical with the quartz-porphyries of the Zoetlief beds of Vryburg. They show the same corrosion of the quartz-phenocrysts, the pseudomorphs after enstatite, the alteration of the felspar, and an extensive silicification of the whole rock.

Some specimens from De Beers at 1,400 feet and the Kimberley mine at 2,160 feet are orthoclase-porphyries, while a rock from the 1,400 foot level of the former, practically at the junction with the Pniel diabase, is an extremely fine-grained chert.

The relation of the Pniel series to the acid volcanics, as shown by the mine sections, will be considered later. (p. 98).

B. The Pniel Series.

The term "Pniel Rocks" was employed by Stow in 1873 in his description of the amygdaloidal and associated rocks of the Vaal River valley. The volcanic rocks contain interbedded quartzites and conglomerates, which, though not often exposed, constitute no small proportion of the total thickness of the formation.

These beds are exposed east of the Harts-Vaal River, wherever the covering of the Dwyka series has been denuded away, and they form all the high ground along the Vaal River.

* R. H. Rastall. Rept. South African Assoc., Adv. Sci. for 1906, p. 275, 1907.

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Owing to the isolated nature of many of the outcrops and to the difficulty with which the bedding planes in the lavas are recognised, it is neither easy to make out the exact succession nor to estimate the thickness of the formation.

The following may be considered to represent roughly the succession, though this is subject to variation in different areas:—

3. Zone of porphyritic lavas: diabase, porphyritic diabase, quartz-porphyry, and quartzite.
2. Zone of normal diabases.
1. Zone of quartzites and conglomerates, with diabase intercalations.

Tuffs, breccias, and brecciated lavas occur in all three zones.

Commencing the description with an account of the development in the Kimberley mines, we find that the surface of the rhyolite undulates, and has no constant direction of slope; there is a fall of 190 feet between the De Beers and the Kimberley shafts. The main quartzite does not rest directly upon the rhyolite, but is separated from it by a bed of diabase, varying in thickness from 72 to 50 feet, the thinning taking place in a southerly direction.

The very lowest layer of the quartzite (at 1,528 feet in the shaft of the Kimberley Mine) is practically a conglomerate, and is crowded with pebbles of quartz-porphyry, granite and quartzite, and fragments of quartz and hard black slate. Inclusions of diabase are absent, and the presence of quartz-porphyry indicates the unconformable nature of the junction of the Pniel with the Zoetlief series, thus confirming the conclusions arrived at from a study of the Riet River sections.

The quartzites vary in thickness from 651 feet to 826 feet, and have a dip of between 4° and 5° almost due south; the thinning takes place in a south-south-easterly direction. The same bed of quartzite has been proved in the Wesselton mine, but the shafts at Bultfontein and Dutoitspan are not yet deep enough to reach it.

From the sections of the mine shafts and a plan showing their positions, it is possible to determine the strike of the uppermost bed in the quartzites at a depth of from 600 to 700 feet below the surface. At the Kimberley Mine the strike is nearly east and west, but this curves round to south-east at the Wesselton mine. From this point it passes into the Orange River Colony, apparently with a nearly uniform curvature, and appears at the surface on the north bank of the Modder River, along the Cape Colony boundary line. The quartzites form a little ridge on Voetpad's Drift (Fig. 1), and dip north-westwards below the diabase. Dips vary from 5° to 30°, and the strata are traversed by small flexures having axes trending north-westwards. The thickness of the series cannot be less than 600 feet here.

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On Dooms diabase appears below the quartzites and above the rhyolites; westwards on Van Aswegens Hoek this lower volcanic group thickens at the expense of the sedimentary rocks, so that on the Riet River, where there are continuous cliff-sections, the rhyolites are succeeded by diabases only.

The quartzites are followed by basic lavas, which are well-exposed in the railway cutting a mile and a half north of Modder River Station.

At the small cottage on the railway a second quartzite horizon is found, the thickness of which, as shown by a well, is about 50 feet. The quartzites dip towards the north, and are succeeded by diabase. The band is evidently lenticular, as the outcrops cannot be traced more than about a quarter of a mile on either side of the railway.

The Pniel series have thus been bent into the form of a basin between Kimberley and the Riet River, and the upper quartzite just mentioned finds its equivalent in the Bultfontein and Dutoitspan Mines. In these it has a thickness of 129 feet, and a dip to the south-west of between 2° and 3°. The thickness of the volcanic group separating the two quartzite zones has not been proved in any one shaft, but may be estimated at from 450 to 500 feet. It consists principally of compact and amygdaloidal diabases, but in Dutoitspan Mine, between the depths of 550 and 560 feet, there are pebbly grits and tuffs.

The maximum thickness of the Pniel series at Kimberley will be about 1,575 feet.

The nearest outcrop to Kimberley of the diabase is at a point six miles out, a little south of the road to Barkly.

After leaving Kimberley, if we except the Riet River area, no sedimentary rocks belonging to the Pniel series are seen for many miles—not until we approach either Pokwani, Delport's Hope, Schmidt's Drift, or the Orange River.

East of the railway and parallel to it is an anticline extending from Taungs past Pokwani, and bringing up from beneath the diabase a considerable thickness of conglomeratic rocks.

This belt is about 21 miles in length, with an average width of 4 miles; the anticline has been greatly cut into by rivers taking their rise on the plateau to the east, and the western limb is considerably denuded.

The material building up the core of the anticline varies extremely in nature, both along and across the strike, but, generally speaking, it is a gritty felspathic rock, containing pebbles, and passing into an arkose in one direction, and into a conglomerate in the other.

At Taungs the lowest beds exposed are grey grits and quartzites, at least 250 feet thick, along the south side of the Harts River. Just below the Court-house is a cliff of massive blue-black flinty rock, fully 20 feet thick, and forming a shallow anti-

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cline pitching towards the north. It is followed by a succession of grits and conglomerates, and the total thickness of strata exposed at Taungs must be fully 500 feet.

The pebbles are either scattered through the rock or crowded together with hardly any cement to form lenticular layers, with a thickness of as much as eight feet.

Immediately north-east of Taungs the conglomerates dip directly below the diabase. About four miles to the south-east, just below the top of the series, is a band of black chert, followed by ashy beds full of masses of amygdaloid, and overlain by sandstones with thin sheets of lava.

The pebbles in the conglomerate are all smooth and waterworn, and are seldom over a foot in diameter, although one of two feet in length was found. They consist of quartzites of various colours, black and banded cherts, quartz-porphyry and orthoclase-porphyry, quartz, and less abundantly felsites, amygdaloids, chert breccia, pebbly quartzite, jasper, and banded ironstones (magnetic quartzites).

The inclusions, especially the quartzites, show peculiar etchings, pits, and circular or oval lines of erosion, while the banded quartzites and cherts have irregular grooves along the planes of bedding. The porphyry pebbles almost invariably have the felspar crystals removed on their exteriors, and sometimes to a depth of a couple of inches the felspar has been changed to a soft pinkish material. Hence such pebbles show deeply-pitted exteriors.

Upon breaking out the pebbles from the conglomerate, it is seen that this etching and pitting must have taken place prior to their having been embedded in the matrix. Very probably the conglomerates were formed off a coast, along the shore of which the pebbles had been rolled and exposed to the weather for a considerable time before their entombment.

Near Pokwani, on the farm Bawtree, in the western limb of the anticline, there appear below the diabase coarse conglomerates, cropping out in great angular and rounded masses, and reminding one forcibly of the conglomerates at Mafeking. A remarkable point is the great abundance of fragments of granite gneiss and pegmatite, along with magnetic-quartzite, ferruginous chert, various schists and vein quartz, all well rounded and often in boulders several feet in diameter. The dip is rather steep beneath the diabase, and there are in a few places thin volcanic flows among the conglomerates.

On the farm Rockdale arkoses occur toward the top of the formation, with the bedding planes feebly developed, and form great rounded masses. They contain small pebbles, quartz-porphyry being the most abundant constituent, and thus recall the conglomerates of Botman's Poort.†

† Annual Rept. Geol. Com. for 1905, p. 239.

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On the farm Pokwani the lowest strata exposed in the anticline are seen to consist of very soft greenish shales, followed by grits. Between these and the upper series of grits and conglomerates is a thin sheet of amygdaloid, which on being followed to the south rapidly thickens, and on Eastwood covers a fairly large area. It includes thin beds of grit and pebbly sandstone.

The anticline pitches southwards below the diabase just before reaching the Transvaal boundary line. The volcanic rocks which overlie the conglomerates are generally compact and vesicular diabases; occasionally there are tuffs and breccias, while at the beacon H.2, close to Pokwani Station, they contain quartzitic bands, and are associated with a gritty conglomerate, carrying well-rounded masses of various types of diabases and amygdaloids.

The trigonometrical pile of Kopje Enkel stands upon quartzites and black cherty rocks. Diabase is seen a short distance to the north, and the beds probably correspond to the Pokwani conglomerates.

A most peculiar feature about these conglomerates is that, although they attain such a thickness at Taungs, they are nevertheless absent at Modimoe, where, as already recorded, the diabase rests directly upon the granite. It is clear that the conglomerates have been deposited at the foot of a ridge composed of granite, quartzite, quartz-porphyry, and banded-ironstones belonging to the Kraaipan Formation, rocks which are known to occur along the Harts Valley, in the Bloemhof Division of the Transvaal.

Directing our attention now to the south, we find that these basal deposits of the Pniel series are brought up by an anticline, which extends from Hopetown to Campbell, and which is crossed by transverse flexures.

On the Orange River, just below Hopetown, the beds are exposed on either bank, and consist of various sandstones, quartzites, and grits to a thickness of at least 150 feet. Some of the grits are conglomeratic, and contain rows of little pebbles of quartz and more rarely of dark quartzite. This stone can be obtained in large slabs, and has been quarried for the construction of the road-bridge.

On the south the strata are overlapped by the Dwyka boulder-bed, and on the north they are overlain by a great thickness of coarse volcanic breccias.

The junction with the overlying volcanics is well seen on the left bank of the river, a little above the bridge. On the opposite bank the succession is duplicated by a small fault.

In a deep lateral gorge of the Orange River, on Eskdale, there appears a tiny inlier of the quartzites, overlain by compact diabase. From this point the strata rise, and the quartzites form a dome near the top of the ridge, a couple of miles to the north.

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From Summerhill to Clydesdale, a distance of eighteen miles, there are continuous exposures of quartzites along the anticline. In pre-Dwyka times the crown of the anticline was denuded, and an anticlinal valley formed, which laid bare the underlying granite. This valley, but slightly modified, exists at the present day, the greater proportion of the conglomerate and shale which at one time filled it in having been removed by denudation. Both to the north-east and south-west the quartzites form cliffs, while on Summerhill, at the end of the pitching anticline, they give rise to a fine amphitheatre. From Ettrick to Tullochgorum the southern limb of the anticline is faulted, and the granite is brought up against the diabase; the actual contacts are concealed by the Dwyka.

On Clydesdale the arch of the anticline remains intact, and it has a somewhat flattened crest, thus approaching in character a double monocline. The northern limb forms an elevation known as Slijpsteen ("Whetstone") Kopje, which was visited and described by Stow.‡

On Stratford the anticline pitches below the diabase, but the quartzites are brought up immediately beyond by an anticline striking north-eastwards, and form a ridge overlooking Douglas and the Vaal River.

The fold into which the quartzites have been bent pitches to the north-east, while its western limb has been denuded away and hidden by the Dwyka formation and by red sand. A most remarkable feature is the extraordinary false-bedding in the quartzites, very well exhibited a little to the south of the main road to Belmont. The inclination of one set of laminae to those immediately above or below may reach a value of 80°, and in consequence, the deviation of a lamina from the normal plane of bedding cannot be less than 40°. The quartzites are brought up by a similar transverse fold on the right bank of the Vaal River, on the farm Atherton, a little above Douglas, where they contain shaley layers.

The strata exposed in all the anticlines are principally light-grey glassy quartzites. Soft creamy coloured sandstones and arkoses are represented as well, commonly in the middle portion of the formation; they have been utilised for building purposes and for grindstones.

On Hereford a well passes through the base of the formation into the granite, the strata consisting of flaggy sandstones, micaceous shales, and arkoses. On Summerhill the beds resting directly upon the granite are hard quartzites.

The quartzites are occasionally gritty, and contain small pebbles of quartz; they are sometimes traversed by small irregular quartz veins. The thickness of the formation must be somewhere between 200 and 300 feet.

‡ G. W. Stow, *loc. cit*, p. 597.

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In Herbert the rocks which succeed the quartzites are entirely of volcanic origin, *e.g.*, diabases and amygdaloids, flinty-looking rocks, light-coloured (probably andesitic) lavas, breccias, etc.

East of Schmidt's Drift there are a few outcrops of quartzites in the midst of the volcanics. At Hofmann's Pan there are flags and white quartzites, both overlain and underlain by diabase and about 25 feet in thickness. The same horizon is probably represented by quartzites and flags on Klip Fontein, about six miles to the north, at the foot of the great ridge flanking the Vaal River. A fold brings up the same band midway between Hofmann's Pan and Schmidt's Drift, on the north side of the main road.

The uppermost zone, characterised by the presence of porphyritic lavas, occupies small areas on both banks of the Vaal River below Waldeck's Plant. The lavas dip towards the north-west, and consist of green compact diabases, carrying large felspar phenocrysts.

On the farm H.V. 47 there is an intercalation of quartz-porphyry, which is more or less on the same horizon as the quartz-porphyry forming two kopjes at the extreme southern corner of Droogе Veldt. These little hills rise from a base of diabase, and the rock of which they are composed is sometimes vesicular and shows fluxion structure.

Patches are also seen on Klip Fontein, within two miles' distance, but are more slaggy and seem to be less acid. From Waldeck's Plant to Delport's Hope there are alternations of diabase, amygdaloid, porphyritic diabase, and breccias, and at Sydney there is an intercalated bed of quartzite, not more than 20 feet in thickness. The quartzites weather with a rough brown exterior, and contain great numbers of spherical concretions from a half an inch to an inch in diameter. Certain gritty bands contain small quartz pebbles up to a quarter of an inch in size. The strata are affected by gentle folds trending north-eastwards; the general dip is down the river. The quartzite is succeeded by very coarsely porphyritic diabases, which are well exposed on the left bank of the Vaal only.

Porphyritic diabases are found in a few other localities, but it is not certain whether they belong to this or to a lower horizon. For example, they appear on Graspan, midway between Kimberley and Schmidt's Drift, at Koppie's Kraal on the Riet River, and at the southern corner of Stratford, on the Orange River.

Lithological Characters.—The lavas are usually so greatly altered that it is only in few specimens that the original minerals can be made out.

A compact variety from Riverton shows in thin section (1560) granules and prisms of quite fresh augite accompanied by a little chlorite, epidote, and calcite. The felspar is in the form of stout laths, and appears to be andesine.

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Mr. Rastall has given a description of several lavas from the Kimberley mines,‡ while De Launay* has given a few analyses of the diabases.

The porphyritic lavas appear to have phenocrysts of orthoclase; these may attain a length of an inch. In thin section (1573) the greenish-yellow waxy-looking felspar is found to be altered entirely to epidote and zoisite, but the ground mass consists of minute plagioclase laths, small augites, and a little epidote and sometimes quartz. In many of the lavas the augite has been entirely converted into fibrous hornblende (uralite). Some of the more acid-looking varieties may be andesites or dacites, while trachytes may also be represented.

A remarkable feature about the Pniel volcanics is the great proportion of brecciated igneous material in them, which sometimes forms beds from 25 to 50 feet in thickness, traceable for miles. The breccias are often veined with black cherty material, possibly representing fine sediment, which was deposited in the spaces between the rock fragments. Some lavas contain oval or rounded masses of volcanic rock of a more acid type, and resemble the variety known as "pillowy-lava."

Pipe-amygdaloids are not uncommon. Good examples were obtained from the Kimberley Mine and from Rust-en-Vrede and Gras Randt, both on the Kimberley-Schmidt's Drift road. Lavas containing "vesicle-cylinders" are numerous, for example at the town of Barkly West and at Niekerk's Rush.††

Fissures of Eruption.—No vents or fissures from which the Pniel volcanics could have issued have yet been found. There are, however, many peculiar veins or dykes of felsitic material, which are confined chiefly to the farms Klip Fontein and Rooi Poort, north-east of Schmidt's Drift. Their course is nearly east and west, and their outcrops run in straight lines, regardless of the contour of the diabase surface. They vary in width from a few feet up to ten or fifteen, and though well-defined from the surrounding diabase, do not appear to have sharp junctions.

These dyke-like masses consist of light pink or cream-coloured felsitic rock, mostly compact, sometimes vesicular, and are commonly much brecciated and silicified. As there are outliers of acid amygdaloid and quartz-porphyry a little to the east, I think that possibly these dykes mark the sites of fissures from which the higher-lying acid volcanics may have issued. At the junction with the ascending acid magma, the diabase would be partially fused, and there would necessarily be an intermixing of the two materials.

Conditions Attending the Formation of the Pniel Series.—In the area to the north it was pointed out in last year's Report that the floor upon which these rocks were formed was an ex-

‡ Rept. South African Assoc. Adv. Sc. for 1906, p. 272.
* De Launay. Les Diamants du Cap., p. 109. Paris, 1897.
†† Geological Magazine, p. 15, 1907.

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tremely diversified one, probably an old land surface. In the south this surface seems to have been much more even and regular, and very probably a submerged area.

The oldest rocks are the lava flows succeeding the rhyolite at Kimberley and on the Riet River. This preliminary volcanic outburst was succeeded by a period of sedimentation, during which from 200 to over 800 feet of quartzites and conglomerates were deposited, evidently over a wide area.

With the Taungs conglomerates must be grouped those of Botman's Poort, the exact position of which was uncertain at the time of writing the last Report. Similar quartzites and conglomerates have been found below the diabase in the neighbourhood of Schweizer Renecke, Wolmaranstad, and Kunana by Mr. Holmes, and at Klerksdorp by Dr. Jorissen,† from which it seems very probable that they represent the Elsburg Series of the Witwatersrand.

The pebbles which the conglomerates contain, together with more direct evidence, indicate an unconformity with the granite, the Kraaipan formation, the Witwatersrand formation, and the Zoetlief beds.

That the succeeding period of volcanic activity was accompanied by sedimentation is indicated by intercalations of volcanic and sedimentary material, but in the north, and perhaps in places to the east as well, the volcanic rocks rest directly and unconformably upon much older formations. There is accordingly a great overlapping of the volcanic rocks, and the lavas occupy a tract far exceeding in size the area covered by the sedimentaries.

In Prieska the diabase rests directly upon the older formations, and it seems probable that the original basin was limited to the interval between Vryburg and Prieska. Already the quartzites along the Orange River show by their diminished thickness the nearness of the source of the sedimentary material.

III. THE BLACK REEF SERIES.

Owing to the wide area occupied by the Dwyka formation in the valleys of the Harts, Dry Harts, and Vaal Rivers, the Black Reef series is but infrequently exposed. After leaving Dry Harts Siding, the formation first appears at Borrell's Kopje, near Delport's Hope.

The rocks are flagstones and quartzites, which are succeeded on the west by limestones and dolomites with interbedded shales. A couple of miles east of Delport's the beds form an irregular dome, the strata being chiefly green or grey flagstones. West of the Vaal River, from the Barkly West boundary as far as Douglas, the Black Reef series forms disconnected outcrops, and has a low dip towards the Kaap Plateau.

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† G. G. Holmes, Trans. Geol. Soc. S. A. Vol. IX., p. 93.
E. Jorissen, do. do. do. p. 41

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On the farm Roode Kopjes, midway between Douglas and Campbell, the strata are bent into a dome, the core of which is formed by amygdaloidal diabase. A similar though much smaller dome is seen to the south. The western beacon of Brij Paal Commonage stands on the hill which it makes.

On the east of the Vaal River, near Schmidt's Drift, there are two patches of Black Reef, the larger of which, on Zaand Plaat, forms a somewhat flat-topped hill.

Lithological Character of the Black Reef.—Throughout this area this formation is of very similar character to the Black Reef series in the Vryburg Division.

Usually it is rather flaggy, and some of the material can be termed shale. Such soft greenish shales are very well developed towards the base of the series east of Schmidt's Drift, and are excellently exposed in the cuttings along the main road in its descent to the pont. In some localities, *e.g.*, N.W.4 and N.W.5, on the Barkly West boundary, the material is altogether a massive quartzite, and a full section from the diabase up to the Campbell Rand series is seen on the side of the ridge carrying the boundary beacon. Usually the formation becomes shaly towards its upper limit.

Thin limestones and dolomites then appear, and become more and more numerous, until the shales form an insignificant proportion. It is thus rather difficult to draw a sharp divisional line between the Black Reef and the Campbell Rand formations.

Dark green quartzites are well represented, while at Schmidt's Drift there is an intensely black massive quartzite, sometimes carrying large inclusions of black-green chert, containing rhombohedra of siderite. These cherts have all the appearance of boulders, but are more probably concretions. On N.W.3 this variety of chert forms a bed nearly a foot thick, and is crowded with rhombohedra of siderite about one-third of an inch in size. It also forms oval, round, flattish, or irregular masses in the quartzite, while there are as well beds of cherty flagstone with much smaller rhombs. The carbonates usually weather out, and leave honeycombed masses of chert.

Grits are very rare—I only noticed them on the northern part of Roode Kopjes—while conglomerates are absent.

The thickness of the formation appears to be wonderfully uniform, and ranges from 150 and 200 feet.

Relation to the Ventersdorp System.—There are but few sections where the relationship of the two formations can be studied, but the unconformity which they indicate seems to be of no great magnitude; this is a confirmation of the views expressed as the outcome of the work done further north.

At the southern kopje east of Delport's Hope, the base of the Black Reef is found to transgress from a quartzite interbedded with the diabases on to the diabase overlying this intercalation.

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The dip of the latter is much greater than that of the overlying flaggy quartzites.

On N.W.4, just behind the homestead, the basal quartzites rest upon a massive bed of felsite, which is sometimes compact, sometimes amygdaloidal, and often brecciated. The quartzites for a short distance above the base contain fragments of the felsite; one layer is a breccia of felsite fragments in a dark quartzitic ground mass.

To the south the base of the Black Reef comes into contact with basic lavas and breccias, so that there is evidently an unconformity.

It is difficult to be sure what horizons diabases seem to belong to at the various contacts with the Black Reef. I think that the highest zone of the Pniel group is probably represented near Delport's Hope.

IV. THE CAMPBELL RAND SERIES.

From the edge of the Kaap Plateau for many miles westwards extend rocks belonging to this formation. The escarpment does not mark its eastern limit, for patches are found on the slope towards the Harts-Vaal River. The feature is due to erosion in pre-Dwyka times, and a deep gorge must have existed, coinciding almost exactly with the course of the present Harts-Vaal River. This valley was filled in with Karroo beds, and is being re-excavated by the present rivers. The cliff-face varies from 300 to 500 feet in altitude, but must have been much higher originally. West of Delport's Hope the shales still abut against the cliff of limestones, etc., to form a gentle slope, up which the main road to Daniel's Kuil has been carried. The same thing is seen at Boetsap.

Towards Vryburg the divisional line between this formation and the Black Reef series is sharp, and the limestone and dolomite occur in rather thick bands, separated by hard greenish flags. Further south the formation includes a great deal of soft bluish-black shale, and there is a gradual passage into the Black Reef series. North-west of Schmidt's Drift there are splendid sections showing beds of soft shales, sometimes over 50 feet in thickness, alternating with massive layers of limestone and dolomite. On the farm N.W. 71, where there are five such hard bands in the face of the escarpment, one is reminded very much of the flat-topped hills of shale with "defining" sandstone of the Karroo. Some of the Campbell Rand shales are carbonaceous and pyritic, for example at Klip Fontein, midway between Schmidt's Drift and Douglas.

The peculiar unconformity seen at Leij Fontein has been fully described by Mr. Rogers in the last Annual Report.† It is on

† p. 153.

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a horizon at least 500 feet above the Black Reef, and probably somewhere nearer 1,000 feet. It is very interesting to note that the great anticline affecting the Pniel series, and extending from Hopetown to Douglas, continues through the Roode Kopjes to the boundary line between Leij Fontein and Campbell Commonage. It thus seems probable that the anticlinal fold originated, or was partly produced, during the deposition of the Campbell Rand rocks. The lower strata at Leij Fontein have been tilted towards the west and denuded. The unconformity probably runs across the commonage, through the village of Campbell, but the exposures are not numerous enough to determine its position accurately. The eastern limb of the anticline is seen in the escarpment just west of the entrance to the Campbell ravine.

Toward the base of the Campbell Rand formation oolitic limestones are very numerous, and, though only in thin bands, often form horizons that can be followed for miles. The oolitic structures have often the size of a pea.

The limestones are all blue-grey in colour and more or less dolomitic in composition. They contain chert and cherty quartzite, either as beds, lenticles, or irregular masses. The limestones are traversed by little veins or threads of quartz, sometimes forming a network, at other times distributed through the rock in the form of little crystals or crystal aggregates. Analyses of some of these limestones have been given by Mr. R. B. Young.*

V. THE DWYKA SERIES.

The greater portion of this area is occupied by rocks belonging to the Dwyka series, showing that the patches described in last year's Report were but a remnant of a widely spread sheet of deposits of Karroo age.

As in the western part of the Cape Colony, the formation can be roughly divided into two portions: the lower consisting of a boulder-bed and the upper of shales. In this part of the Colony, however, it is impossible to distinguish these divisions upon a map for the following reasons:—*Firstly*, the beds are often hidden over considerable distances by superficial deposits, such as sand, tufa, or gravels; *secondly*, there are often alternations of shale, boulder-shale, and conglomerate towards the base of the formation; and, *thirdly*, erratic boulders occur at a number of localities embedded in the shales at a horizon far above the base of the formation.

The uppermost division of the Dwyka series is constituted by the "white-band," which consists of white-weathering carbonaceous shales. Strata above this horizon will be regarded as

* R. B. Young, Trans. Geol. Soc. S. A. Vol. IX., p. 58, 1906.

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belonging to the Ecca series. This classification was adopted by the Geological Survey in 1897, and its practical utility has been confirmed by each succeeding report. The use of the term Ecca to describe the shales immediately succeeding the boulder-beds in this area (sometimes known as Kimberley shales) is therefore inadvisable, as these beds are not on the same horizon as the Ecca beds of the southern and western Cape Colony as defined by the Cape Survey.

There can be no doubt that the Dwyka boulder-beds have been laid down under glacial conditions. This area has yielded much information concerning the conditions that prevailed during their formation; but many problems, nevertheless, suggest themselves, which can only be solved when some of the difficulties which still beset the study of pleistocene glacial geology have been cleared up.

Surface upon which the formation rests.—Everywhere the Dwyka lies unconformably upon older rocks, over a large area chiefly upon the diabases of the Pniel series. It overlies an undulating surface, at one time a tract of highly diversified land sloping gradually toward the south-west. This surface was intersected by a number of valleys, some of considerable width and depth, extending in a north-north-easterly direction.

During and immediately following the period of glaciation these valleys were filled in with glacial deposits and shales, but the extensive denudation which has taken place since Cretaceous times has re-excavated these ancient valley systems, the softer Karroo deposits being eroded more easily than the hard pre-Karroo rocks. In consequence the courses of the present rivers coincide very closely with those of the ancient continent, as, for example, the Harts-Vaal River. The contours of the ridges formed by the older rocks are smoothed and rounded, and are typically those of a glaciated region; in the case of the escarpment of the Kaap, however, solution of the limestone has effaced all evidences of glaciation.

Variation in altitude of the floor.—So irregular is the floor that it is extremely rare to find any considerable area over which it has even an approximately uniform slope.

Between Riverton Road and Windsorton Road Stations there is a large flattish tract which extends eastwards for a number of miles into the Orange River Colony. Numberless little hummocks of diabase project through the thin covering of Dwyka, and are in places so abundant that it is almost impossible to map all these tiny inliers. The longer axes of the greater number of these inliers strike in a south-westerly direction, and they are apparently the exposed tops of buried parallel ridges.

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In the Harts Valley at Taungs, the variation in altitude of the base of the Dwyka is not less than 800 feet, see Fig. 3, while north of Schmidt's Drift variations of from 400 to 500 feet in altitude are found within remarkably short distances. The same is the case at Douglas; along the Orange River Dwyka is found right down in its bed, while to the north, diabase and quartzite rise above it to an altitude of close upon 700 feet. Everywhere are seen little patches of conglomerate adhering to steep faces of rock, while in not a few localities the conglomerate lies banked up against a steep cliff which originally must have had an altitude of from 200 to 300 feet. As already noted, the present escarpment of the Kaap represents such a feature, and must have had a face rising from 500 to probably over 800 feet in height.

When the minor undulations are considered, it is found that changes in level of the old surface are often very abrupt, and that the slope frequently approaches the vertical; in one case south of Schmidt's Drift a face has even been undercut.

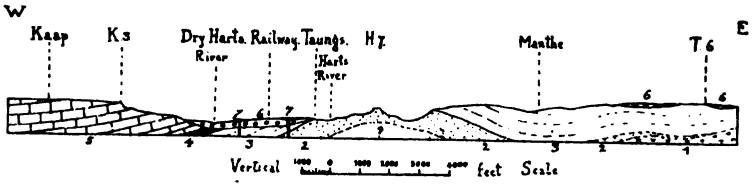

FIG. 3.—Section from Kaap Plateau to Transvaal border, distance 27 miles. 1, granite; 2, conglomerates; 3, diabase and amygdaloid; 4, Black Reef series; 5, Campbell Rand series; 6, Dwyka series; 7, dolerite.

Glaciated rock-basins.—That the irregularities of the surface are due principally to sub-aerial and to river erosion in pre-Dwyka times admits of no doubt, but there is considerable evidence to show that glacial erosion has played no small part and has to a certain degree modified the original contours. The valleys have been smoothed and protuberances rounded off, while rock-basins have in a number of instances been excavated. These basins vary from shallow depressions a few yards in diameter to hollows a mile or more across and of pretty considerable depth.†

We have a very good example about a mile to the south-east of Riverton, with a length of a mile and a half, and a width of not more than half a mile; it is surrounded by a ridge of diabase. Another basin filled in with shale occurs about 2 miles to the south-east of the Leicester mine near Klipdam. It is economically of great importance, since wells sunk in the shale yield splendid supplies of water. Other basins are found to the north, as, for example, at the Cyrus Mine. Probably they are quite

† See Ann. Rept. Geol. Com. for 1905, p. 251.

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numerous, but, in most cases, owing to incomplete denudation, the rim of diabase cannot be traced completely round the lower-lying shale and conglomerate.

The presence of such glaciated rock-basins has determined to a great degree the formation of pans in this area; this will be discussed more fully later on.

Direction and effects of glaciation.—The glaciation of rock-surfaces has been well described by Messrs. Young and Johnson* at various points between Riverton and Prieska; similar striated surfaces have been found at numerous localities, chiefly along the Vaal River.

In the majority of cases the direction of glaciation is from the north-east to the south-west; the following table gives some of the values obtained, the angles in all cases being measured from the true meridian:—

Modder Hoek, H.V.7 (Barkly West)	S. 50° W.
Riverton	S. 81° W.
Kimberley Mine (south side)	S. 50° W.
Pniel	S. 27° W.
One mile north of "The Bend"	S. 37° W.
One mile south-east of the Barkly West Bridge	S. 30—40 W.
H.V. 47 (Barkly West)	S. 54° W.
Longlands	S. 15°—45° W
Schmidt's Drift (east of river)	S. 21° W.
R. 26 (Herbert)	S. 10° W.
Banks Drift (Riet River)	S. 38°—80° W.
Roode Kopjes (between Campbell and Douglas)	S. 55° W.
Backhouse (Douglas)	
Ettrick (Orange River)	S. 42° W.
Hopetown (bridge)	S. 90° W.

Upon comparing the values, it will be noticed that they show a considerable variation, though the mean is very nearly due south-west.

Now it has already been remarked that the pre-Dwyka valleys and depressions have a south-westerly trend, to be more accurate, a bearing of from S. 15°—45° W., usually somewhere about S. 30 W.

This shows that the ice-sheet has crossed the ridges and depressions *obliquely*, and that the movement of the ice has to a great extent been uninfluenced by the contour of the ground.

In accordance with the experience gained in a study of pleistocene glaciation in the Northern Hemisphere, one would be led to expect a deflection of the lower portions of the moving ice along

*. R. B. Young and J. P. Johnson. Trans. Geol. Soc. S. A., Vol. IX., p. 34, 1906.

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the bottom of these valleys while the upper portion overrode the ridges without appreciably diverging from its course. In but few cases is this true here; in the majority the direction of movement seems to have been independent of the ridges and valleys.

A little to the south of Schmidt's Drift the ice appears to have impinged on the ridge of Black Reef quartzites forming the right bank of the river and to have been deflected in a more southerly direction almost parallel to it. Close beside the road at the boundary between R. 26 and R. 27 the quartzites are undercut and show a striated face sloping inwards, while just below it the flags are tilted on edge and the glacial material thrust in beneath them.

The direction of striation is S. 10 W., whereas on R. 25 and 24 (Sivonel Location) it is S. 28 W. Even here, however, the glacial striae are oblique to the *roches moutonnées*, for on Sivonel the longer axes of these hummocks point a little to the *east* of south.

The remarkable parallelism of the hollows formed between these hummocks either points to an old river system with an extraordinarily regular arrangement of tributaries or else argues their excavation by ice. It is, however, difficult to see how a sheet moving in a certain direction could cut in the underlying rock deep grooves which are arranged obliquely to its direction of movement.

It seems more feasible to suppose that the ice-sheet had during its earlier stages a movement directed more towards the south, and that ultimately its course was deflected in a westerly direction, and practically all traces of the more southerly glaciation obliterated by continued erosion.

There are certain irregularities in the distribution of erratic blocks in the boulder-beds which can be very well accounted for on this hypothesis; it must nevertheless be made clear that the evidence is not as good as one could wish for. Little additional light is thrown on the question by the presence of cross-striae.

Cross-striae.—On all glaciated surfaces there is a slight crossing of the striations. As a rule the flatter the surface the greater will be the distance over which the striations maintain their parallelism; the more inclined the face the greater is their divergence.

At Banks Drift, on the Riet River, there are flat surfaces showing two sets of striations, one running S. 38 W. and the other S. 80 W.; in places there are striae intermediate in direction. Here the more westerly striae partly obliterate the others, which tends to support the hypothesis stated above.

Near Riverton the opposite is the case. About three miles to the north-west at the bend of the Vaal (Khosop's Kraal) are fine *roches moutonnées* having remarkably steep surfaces; on these rests the boulder bed.

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At the northernmost outcrop there are long furrows in the glacial material, a few feet wide and up to two feet in depth; they are exposed over a length of 250 feet and have a constant inclination, rising gradually to the south-west.

The material seems to have been gouged out by the ice-sheet; large boulders embedded in this glacial "pavement"† show striations parallel to the direction of the furrows and ridges. A hummock of diabase has protected the glacial conglomerate on its south-west side from complete removal, and has been instrumental in the formation of the pavement. The striations continue evenly from the furrows on to the crown of this diabase hummock, and cross the older and more westerly-directed striae.

The furrows are in some places filled in with more boulder material, in others they are overlain by greenish shales.

Effects of ice pressure.—The production of the glacial pavement just described is an extremely good example of the shearing away of the glacial material covering a ridge. At a number of places in the vicinity the conglomerate is traversed by planes of shear, groovings, etc. At the south side of the bend in the river the diabase is overlain by fine-grained quartzitic material showing striations, often throughout its mass, and troughs and ridges parallel to the direction of glaciation just like the conglomerate.

At Pniel, a short distance from the Kimberley boundary fence, a pale green laminated sandstone, carrying large erratics rests directly upon the diabase. The dip coincides with the inclination of the underlying rock, but at a couple of points the shales have been bent into sharp anticlines probably through pressure exerted by the moving ice-sheet.

To this shearing action of the ice-sheet rather than to subaerial denudation succeeding the period of glaciation may be ascribed the absence of conglomerate in such places where the shales are found abutting against steeply inclined glaciated surfaces or on the crests of glaciated ridges. The squeezing of the glacial material into the flagstones of the Black Reef series south of Schmidt's Drift has already been noticed.

On the left bank of the Vaal River about three miles below Windsorton, the diabase floor is traversed by well-developed joints. The ice-sheet has torn out blocks of diabase about three feet across, and the spaces are now occupied by conglomerate. The "plucking" on the south-west side of joints has been noticed by Messrs. Young and Johnson.

Transport of boulders.—The direction of movement indicated by the striae is confirmed by the examination of the contents of the glacial material, most of the boulders being of rocks which are found ***in situ*** to the north-east.

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† For a description of a similar "boulder-pavement" see the Ann. Rept. Geol. Com. for 1903, p. 21.

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Diabase and amygdaloid are invariably predominant; quartzites, quartz-porphyries, and granites less numerous The Red granite of the Bushveld area of the Transvaal is not common, but its presence shows that some of the boulders have travelled a great distance.

The rhyolites of Klokfontein and of the Riet River are abundant along the Orange River between Mark's Drift and Ettrick. The Dwyka between Schmidt's Drift and Campbell is crowded with fragments of Black Reef quartzite, while close in under the escarpment blocks of the Campbell Rand limestone and chert are numerous, *e.g.*, Kalk Dam and Roode Kopjes. South-west of the granite and quartzite exposures on Ettrick and Hereford are abundant erratics of those rocks.

Much of the material in the Dwyka is of local origin, and in certain cases the inclusions still preserve somewhat angular outlines, for example, in the case of the quartzite boulders at Delport's Hope, which are derived from the ridges lying a little to the north-east.

The boulder beds.—Speaking generally, in the eastern portion of this area, there is a single boulder-bed of no great thickness, succeeded rather abruptly by a series of fine-grained dark shales and fissile sandstones.

The rock is too hard to be called a boulder-clay, while the scarcity of boulders in certain portions prevents the general employment of the name conglomerate; the terms moraine and ground-moraine are hardly justified until we know more about the conditions under which the deposits were formed. Prof. Penck has recently suggested the name "*tillite*," a term which is certainly very convenient to employ.

The rock is harder here than in the neighbourhood of Vryburg, but otherwise has much the same character. It includes numerous boulders of all sizes, mostly well smoothed and striated, while the matrix is a pale bluish, brownish, or greenish gritty material.

The thickness of the boulder-bed varies considerably within short distances; it may be as much as 30 feet or more in one place and thin out to nothing a short distance away.

Generally speaking, it is thicker over the hollows in the floor and thinner over the ridges. Its upper surface reproduces the contours of the floor, but the irregularities are always flattened out. The shales following have frequently dips of over 30° in the vicinity of ridges.

In the lower part of the Riet River, on the farm Badenhorst Fontein, there rise from a terrace cut in the soft shales several mounds strewn with boulders, and which indicate the presence underground of little knobs of diabase over which the boulder material had been evenly spread. Similar mounds covered with boulders occur to the north-east of Schmidt's Drift.

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The boulder-bed is replaced by sandstones and pebbly sandstones along a line running in a south-westerly direction from near Modder River Station to the Orange River.

These sandstones are well seen along the Riet River where they rest upon the granite inlier mentioned at the beginning of this Report.

They are massive sandstones of a pale buff pink or green colour, and have been much quarried, as they furnish a building stone of excellent quality. The bottom layer is softer and contains a few boulders. Thick greyish micaceous sandstones appear in the drift and include thin bands of black shale.

On the farm Doornlaagte a well has proved similar sandstone at a depth of 80 feet.

On the farms Boschman's Pan, Glasnivon, Hayfield and Burton, greenish or purplish gritty sandstones crop out or have been proved in boreholes and rest directly upon diabase. At Kababas Pan there are fine exposures of sandstone both round its south-western side and within the pan itself. They are fine-grained greyish green varieties carrying little flakes of white mica. Bedding planes are but feebly developed, and the rock contains very large concretions and sheet-like masses of hard calcareous sandstone of a yellow-brown colour. In these beds are found small boulders of diabase, granite, quartzite, porphyry, etc., sparsely distributed through the rock and gathered together along certain horizons. The inclusions are well rounded, but no glacial striations were visible on any of them.

Close to a little pan at the south-western corner of Glasnivon these sandstones are exposed and have a purplish tint; they are crowded with well-striated boulders.

To the south-west of this point the Dwyka becomes more normal; but, again, on Ettrick, close to the Orange River, the boulder-bed is overlain by crumbly yellowish sandstone with thick calcareous layers, and is often very gritty.

This belt of gritty and pebbly sandstones has been formed along an old valley, and perhaps represents material which has been brought down from the north-east by a post-glacial river. They are succeeded invariably by dark shales and mudstones.

Glacial deposits of an entirely distinct type are found in the Harts-Vaal River Valley, and are confined almost wholly to this portion of the area surveyed; similar conditions appear to have extended for short distances up the Orange and Riet River valleys.

Briefly stated, this type consists of alternations of "boulder-shale," "gravel-Dwyka," "bedded-Dwyka," shales and limestones, followed by black shales in which boulders are frequently present. A short account of some of these different varieties of deposit will therefore precede the description of the sections in which they are found.

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(*a*) *Boulder-shale.*—This consists of a fine-grained bluish or blackish-green shaly material, in which are set rounded and well-striated boulders of various rocks of all sizes, with no definite arrangement or orientation. The shaly character may in part be secondary and due to pressure.

Attention has been directed by Messrs. Young and Johnson to certain bands which are enclosed by the boulder-shale and lie at all angles. Owing to their superior hardness they project above the surface of shale and form ribs and dyke-like masses. The material of which they are composed varies from a sandstone to a conglomerate. Sometimes the shales in which they occur are contorted, indicating the effect of pressure, but in most cases these gritty bands have been deposited in their present positions.

Through the addition of gritty material the boulder-shale passes on one hand into the normal type of glacial conglomerate and on the other into the variety noted below.

(*b*) "*Bedded-Dwyka.*"—Consists of a gritty and well stratified material, in which are set pebbles and boulders, usually of small size and generally striated.

(*c*) "*Gravel-Dwyka.*"—This is a rather peculiar variety, and consists of an aggregate of little angular or irregularly-shaped fragments of rock with a very small proportion of binding material. These fragments are small, seldom more than a couple of inches across, and very rarely show smooth outlines; they are all of hard material such as quartzite, quartz, and chert.

The rock is dark greenish in colour, and forms beds, lenticles, or irregular masses in the midst of shale or boulder-shale. Being very hard, lumps of it often strew the surface of the ground and thus resemble inclusions in the glacial beds.

"Gravel-Dwyka" probably owes its origin to the melting of masses of ice charged with little fragments of rock.

(*d*) *Limestones.*—All the glacial deposits contain a certain amount of carbonate as a cement. Sometimes the amount becomes so great that an impure limestone or dolomite results, which forms concretions or beds. These calcareous rocks resemble to a considerable degree in their mode of weathering the limestones and dolomites of the Campbell Rand series. Commonly they are fine-grained with little or no visible crystalline appearance; sometimes they exhibit the structure known as cone-in-cone. An analysis of such a rock has been given by R. B. Young† under the designation "Ecca Limestone."

Very often the calcareous material takes the place of the matrix in the glacial conglomerate, and extremely tough conglomeratic masses are produced more or less concretionary in character.

† R. B. Young, Trans. Geol. Soc. S. A., Vol. IX., p. 63, 1906.

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The finest section in which all of these varieties of deposits can be studied is found along the south bank of the Riet River, a few miles above its junction with the Vaal (on the farm De Kalk).

The river makes a great bend, and flows at the base of a cliff about one hundred feet in height and almost a mile in length. The strata has been protected by a capping of calcareous tufa and gravels, and an unusually steep face has in consequence been produced.

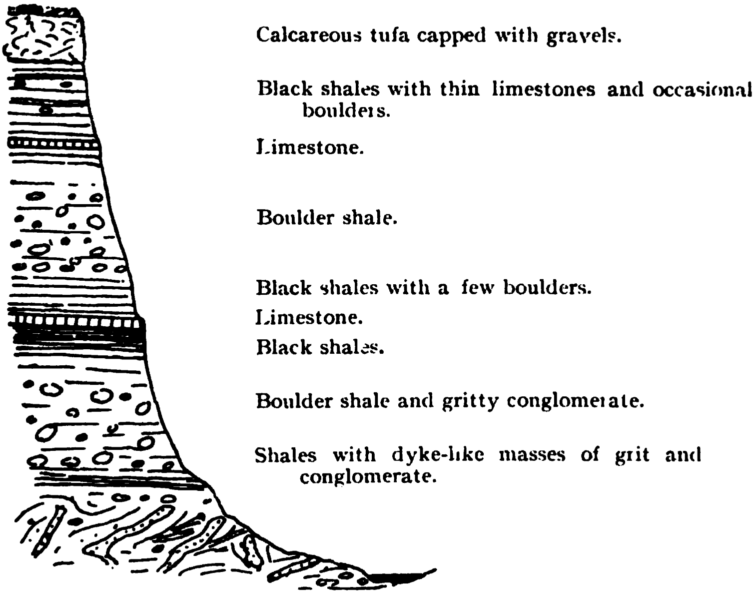

FIG. 4.—Section on Riet River at a point four miles above its junction with the Vaal. Height of section about 100 feet.

The section (Fig. 4) shows shales and boulder-shales, with the peculiar ribs of grit and conglomerate already recorded, at the foot of the cliff; the base of the Dwyka is, however, not seen here. Then follow boulder-shale and gritty boulder-rock with numerous large and well-glaciated inclusions. Next come black shales containing a few scattered boulders, and then a very persistent limestone band, varying in thickness from 6 to 18 inches; the succession is partly repeated, the uppermost strata consisting of black shales and thin limestones and containing occasional boulders always well striated. To the north they are followed by dark fine-grained sandstones and flagstones.

On the farm Atherton, close to Douglas, but on the right bank of the Vaal, there is a fine cliff of boulder-shale fully 80 feet in height; the material is rather uniform in nature, but there are

irregular lenticles and bands of gravel-Dwyka; the finer-grained portions are composed principally of angular debris, while the coarser are full of large glaciated boulders. Diabase and diabase breccia form ridges and islands in the river at the base of the cliff.

On St. Clair and Backhouse there are similar exposures of boulder-shale with layers of shale and bedded or gravelly material. The rock at the base of the formation is usually very hard.

A description has been given by Stow* of a succession behind the old church at Backhouse; the strata are not very well seen here, however, and it seems that he must have obtained his section by piecing together the results obtained from a number of exposures. Since the dip of the the formation and the character of the material changes from point to point, it is very probable that Stow has reckoned the same bed more than once, more especially as the floor of diabase is exposed up the river and behind the old church.

Fine exposures of glacial beds are found on the Vaal River at the Sivonel Location (R. 24) between Douglas and Schmidt's Drift.

The boulder-shales are traversed by gritty ribs and bands, and there is much gravel-Dwyka, calcareous bands and patches, and beds of gritty stuff. The material is well-bedded and the boulders are arranged in layers which can be followed for long distances along the cliff face.

North of Schmidt's Drift, both on the east and west sides of the river, the shales contain beds of limestone, some of which attain a thickness of two feet.

In the Harts River Valley boulders are found in a few localities in the shales at a considerable distance above the base of the formation.

On the Majagoro Location there is a little flat-topped ridge, close in under the escarpment of the Kaap, formed by greenish shales with a thin cap of sandstone and dolerite. Embedded in the shales are boulders of granite, pegmatite, gneiss, diabase, grit, chert, dolomite, etc., some of them being well striated, others being but slightly rounded or angular.

Further down the valley, on the west side of Cornforth Hill (Shaleng) are shales with large calcareous concretions and numerous foreign boulders.

Other localities are Rutland's Drift and a point about four miles east of Espag's Drift on the road to Border Siding.

Similar geological conditions must have prevailed along the lower part of the Riet River. On the north-east side of the farm Kaffir's Dam, about a mile from the river, there is a conical hill composed of blackish shales with calcareous ribs and nodules, and crowned with a little pyramid of dolerite.

* G. W. Stow. Quart. Journ. Geol. Soc. Vol. XXX., p. 598, 1873.

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In the shales are boulders of granite, quartz-porphyry, diabase, quartzites, dolomite, etc., sometimes over a foot in diameter. They are smooth and coated with a film of greenish shale, but no undoubtedly striated ones were found. This horizon must be at least 200 feet above the top of the boulder-bed, for the latter is well exposed along stream courses close to the bank of the river.

Conditions under which the boulder-beds were formed.—Just as in the Northern Hemisphere, so also here it is difficult to imagine the exact way in which the glacial deposits have been formed. The commonly accepted view of a boulder-bed or sheet of till as being a "ground-moraine" and having been formed below a sheet of ice is perhaps hardly in accordance with observations, nor does it adequately explain all the facts.

Judging from the evidence in this area, it seems to me that all these various deposits have almost without exception been formed *beyond the ice-front, and during its retreat* in a northerly or north-easterly direction.

Over the high ground the glacial material would be deposited continuously by the melting of the ice, etc.; while in the valleys (*e.g.*, Harts-Vaal) where the old floor was submerged the deposit would be more or less regularly bedded. Beyond the ice-front material would be deposited by floating ice, while sub-glacial streams would transport gritty and finely divided stuff. The scouring action of running water in certain of the valleys might lead to the partial or complete removal of the glacial material and the formation of fluviatile deposits.

The retreat of the ice-front would not necessarily be continuous, and an advance would result in the ploughing up of the earlier deposits and the production of boulder-pavements.

As the ice retreated the crust of the earth subsided, and the boulder-beds were succeeded by shales and mudstones, with thin sandstones. The occurrence of sporadic boulders in the upper shales indicates the presence of floating ice. This points to a somewhat protracted period of glaciation.

The Upper Shales.—The shales overlying the boulder-deposits consist of blue, green, or black shales, hard mudstones, occasionally flagstones and thin beds of grey and dark sandstone. These are the Kimberley shales of Professor Green. Some of the shales have calcareous and ferruginous concretions, and often they contain a considerable amount of iron pyrites. Indistinct remains of plants are frequently met with.

The thickness of these shales very seldom exceeds 300 feet.

The upper portion of the shales is highly carbonaceous, and on weathering becomes perfectly white, thus forming what is known as the "White-Band."

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The White Band.—The shales are hard and fissile, pure white, with sometimes a slightly grey tint. They contain bands of reddish shale and highly ferruginous and ochreous ribs. Limestones are rather rare and the chert band so well seen in the western and southern Karroo is absent; some of the shales, however, have small cherty concretions.

The white band is seldom well exposed. It is usually overlain by dolerite, and fallen material commonly hides the outcrop. There are good sections just north of the Orange River along the railway, while a few miles to the east there is a conical hill of white shale on the farm Suffolk.

Continuous sections are present on Devondale and Donnybrook, each of the railway, and on Grange, Leinster, Kildare, etc., west of the latter. Further north white shales are seen on Lovedale, Arnotsdale, Richmond, and Thornhill, between Belmont and Douglas, while a splendid section is obtained on the southern face of Kababas Kop. The thickness of the shales here is about 50 feet; elsewhere it is thinner.

The most northerly point at which this band was clearly recognisable was at the summit of a little conical hill on the farm Stofputs, to the south-west of Kimberley. When freshly exposed the beds are black, and it is very probable that the uppermost portion of the carbonaceous shales at the Kimberley mines represent a portion of the "White-Band," for whitish shales are exposed a little to the west of the Kimberley Mine.

South of the Orange River the White-band is found between Hopetown and Orange River Station, and east of the railway on the farm Elandsdraai. It is succeeded by shales of the Ecca series.

Fossils.—Indistinct impressions of plants are abundant in the shales, while long flattened stems are characteristic of the white-band. A fragment of what appears to be a *gangamopteris* was found at Koodoes Berg Drift, on the Riet River, in a shale containing a few glaciated boulders.

The "white-band" of the Herbert Division has yielded specimens of the small reptile *Mesosaurus*, but unfortunately the exact localities cannot be identified. The remains obtained by Gervais† came from a point north of the Orange River.

Günch‡ obtained fragments of a form which he named *Ditrochosaurus* (probably a young *Mesosaurus*), both from the Kimberley Mine and from a point on the railway just north of the Orange River Bridge.

The specimens described by Seeley†† came (1) from the Albania Field-cornetcy of Herbert; (2) as inclusions in the blue-

† P. Gervais. Mém. de l'Acad. de Montpellier. Sec des. Sc. VI., p. 172, 1865.
‡ Gürich. Zeits. de. Deutsch. Geol. Ges. Vol. XLI., p. 641, 1889.
†† Seeley. Quart. Journ. Geol. Soc. Vol. LVIII., p. 586, 1892.

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ground of the Kimberley Mine, being derived from strata which had fallen down into the pipe; and (3) from shale a quarter of a mile to the south-east of the Market Square, Kimberley.

From the white-band on the farm Richmond, west of Belmont, a few fragments of shale were obtained, being portions of a cast of a small reptile which Dr. Broom thinks is probably not a *Mesosaurus*.

The reptile *Mesosaurus* seems to be confined to the "white-band," and may be taken as the zone fossil of the uppermost beds of the Dwyka formation. It has been found in Bushmanland|| on the same horizon.

VI. THE ECCA SERIES.

Succeeding the White-band are greenish and bluish shales, which must be classed with the Ecca, but which are seen at only a few places within the area surveyed.

At Kababas Kop about 15 feet of such beds intervene between the white-band and the dolerite, while on the farm Suffolk the conical hill of white shale is crowned with about 10 feet of bluish-green shales.

The shales forming the base of Kols Kop are in great probability of Ecca age.

The main area of Ecca beds lies to the south of Orange River Station, the passage from the Dwyka being considerably obscured by dolerite sills; these beds have not yet been examined.

On the farm Elandsdraai, east of the railway, some fish-scales were found at the base of the formation.

VII. THE INTRUSIVE ROCKS.

A. Intrusions of Pre-Karroo Age.—A little to the west of Barkly is a sill of diabase which has been intruded parallel to the bedding planes of the volcanic rocks, and consequently dips towards the east.

In thin section (1562) under the microscope it is found to consist of large green fibrous hornblendes (uralite), derived from augite, a core of the latter mineral appearing in a few of the crystals. Original brown hornblende occurs as a border to the uralite. There are three varieties of felspar—a considerable amount of clouded, almost opaque, felspar, probably orthoclase, a fresh oligoclase in prisms, and a colourless felspar containing microlites and inclusions, and evidently the last mineral to crystallise. Magnetite is also present.

A dyke of diabase of a very similar type cuts vertically through the volcanics east of Pokwani, and possesses an easterly strike.

|| Broom. Trans. S. A. Phil. Soc., Vol. XV., p. 104, 1904.

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In thin section (1559) we find the same intergrowth of brown hornblende and uralite. Magnetite is abundant, and small patches of a micrographic intergrowth of quartz and felspar are also present.

A rather curious rock comes from the shaft of the Kimberley Mine, where it forms a dyke about three feet wide in the quartzites of the Pniel series.

The thin section (1080) shows a medium-grained rock containing pale brownish augite, with, as a rule, idiomorphic outlines. Each augite crystal encloses commonly a pale enstatite, or more generally each crystal of enstatite is flanked by augite. The enstatite is mostly altered to slightly greenish bastite. Biotite is abundant, always in small patches, usually attached to the pyroxenes or to the ilmenite, the latter occurring in crystal plates. All these minerals are enclosed by colourless felspar, which very rarely shows any trace of albite twinning, and is probably orthoclase. A great portion of it is replaced by a colourless fibrous material, probably some kind of zeolite. Quartz is present in small quantity.

The rock, though not showing the typical structure of the vogesite division of the lamprophyre group, approaches that class of rocks most nearly. Mr. Rastall has described a somewhat similar rock, also from the Kimberley Mine.

B. The Karroo Dolerites.—Dolerite dykes are practically absent, and the endless succession of ridges and flat-topped dolerite hills are formed by one single sheet, now much denuded, but at one time continuous over almost this entire area.

At Orange River Station and again east of Belmont, along the Orange River Colony boundary, there are dolerite sheets passing obliquely through the Karroo strata, but with these exceptions only the lowest of the intrusive sheets of the Karroo is here represented.

The sheet is remarkably regular in its mode of occurrence, but in a few places it is split up by one or more layers of shale or sandstone. A good example of this is seen to the north of Windsorton Road Station. As a rule, the strata which at one time existed above the sheet have been altogether removed. There is one notable exception, at Wolvedam, 14 miles west of Kimberley, where a small patch of highly altered sediments still remains capping the dolerite. The shales both above and below the dolerite, more particularly the former, have been intensely altered, and converted into black lydianite and hornstone, while the more arenaceous portions have been changed into prismatic quartzite.

This alteration of shales by the dolerite is very frequent, but the intensity of the induration seems to vary considerably. The Leeuw Berg, east of Douglas, is another good locality where extensive metamorphism can be observed. The dolerite has been intruded entirely in the Karroo shales, and almost invari-

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ably at some distance above the base of the Dwyka formation. This distance varies from about 400 feet down to 100 feet. As a rule, however, the intrusion occurs on a horizon not far below the "White-Band" of the Dwyka, sometimes a little above it. Now the base of the Karroo formation, as already shown, varies considerably in altitude from point to point; the dolerite sheet tends to follow these variations of level—at least, the major undulations. For example, considering a section from Windsorton Road westwards towards the Kaap, we first of all find the dolerite extending nearly horizontally. Towards the west it rises slightly, but from the Vaal across to the Harts valley the sheet has been removed by denudation from the great ridge of diabase which forms the watershed between those two rivers.

Near the Frank Smith mine the Dwyka and dolerite come in again with a marked westerly dip; at the Harts River they are both horizontal; from the river up to Boetsap the dolerite rises, and its easterly inclination becomes great enough to prove that in former times its extension must have taken place westwards in the midst of the Dwyka shales which once overlay the limestones of the Kaap.

Thus we find a variation in altitude of at least 500 feet occurring within a distance of a few miles.

A similar rapid variation in altitude corresponding to that of the Karroo floor is well seen along the Kimberley-Schmidt's Drift-road, between the 18th and 26th milestones. So regular is this rising and falling of the base of the dolerite that it seems possible that in places where the Karroo floor is entirely hidden its principal undulations may be inferred from those of the dolerite at the surface.

When this is tested we find that the dolerites dip towards certain axes which run in a north-easterly direction, and therefore more or less parallel to the depressions along the Vaal and Harts Rivers, in which the Dwyka formation was deposited. Such "ridges" and "troughs," if we may so term them, are very well seen in the neighbourhood of Belmont, as well as in several other localities. As an extremely good example we may take the Kimberley group of mines, and it will be seen the base of the dolerite rises and falls according to the altitude of the diabase.

From the De Beers mine the diabase ridge can be "traced" underground in a south-westerly direction. From the railway the dolerite dips away to the north-west and south-east, and the pre-Karroo rocks emerge on the Riet River, disappearing further down stream.

At Wolvedam, where the full section is seen, the sheet has a thickness of about 250 feet, but elsewhere the capping of dolerite does not exceed 100 to 200 feet.

Where denudation has been considerable the hills are flat-topped, and consist principally of shale, with a thin cap of

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dolerite, *e.g.*, Vet Berg, Kababas Kop, the ridge on which Moller's Pile is situated, etc. Where the country becomes flatter and the underlying shales have been protected from active erosion the dolerite forms an undulating surface, and on the flats it may decompose to a friable yellowish material, which is frequently concealed by a layer of calcareous tufa. Such a type of country is found around Kimberley, near Secretaris, Riverton Road, Belmont, etc. Excellent supplies of water are obtained from the dolerite in such cases, especially if there is any large area occupied by it. The rock is full of fissures due to the weathering of the material along the joints; this can be very well seen in the open workings of the Kimberley and De Beers mines.

It is a remarkable thing that throughout the area of some 5,000 square miles over which this sheet has been traced there are practically no feeders visible until we approach the Orange River. Some of the molten material must have travelled a considerable distance along the plane of parting in the shales in order to have reached its present position.

Along the Harts River, between Rutlands Drift and Greef Dale, there is a sheet of dolerite which dips westwards below the Kaap; it was probably an important feeder. Further up the valley are a few other minor sills.

The rock forming the great sheet in this area is the usual coarse-grained ophitic dolerite, which may or may not contain olivine. Good petrological accounts of this sheet, as it occurs at Kimberley, have been given by different observers under the various names of dolerite, "basalt," and "olivine-diabase"; there is, therefore, no necessity for any further description.

Later Intrusions of Dolerite.—At Kimberley two small intrusions were noticed which cut through the horizontal sheet of dolerite. The first of these is seen along the road to the Dutoitspan mine, close to the siding which leads to the Power Station. It is about 10 feet in width.

The second is exposed in a trench along the Schmidt's Drift road, almost at its junction with the road to Koodoo's Berg Drift. Both of these intrusions are fine-grained dolerites.

VIII. THE SUPERFICIAL DEPOSITS.

Over wide areas the rocks are concealed by red sand, calcareous-tufa, or gravels, and this is especially true of the lower-lying tracts underlain by the shales of the Dwyka formation. Although some of these deposits, *e.g.*, the high-level gravels and calcareous tufa terraces, must have a considerable antiquity, it is impossible to classify the superficial deposits according to their age, since sand and calcareous tufa are in process of formation at the present day exactly as has been the case in the past. The deposits will thus have to be described according to their lithological characters.

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(1) *Sand.*—The sand, so abundant in certain parts of this area, is entirely absent from others, and we may in consequence divide the country into two portions, one of which is sandy, while the other is not.

Sand is absent on the right side of the Harts-Vaal River, but on the left side there is a pronounced sandy belt extending from the river as far as the foot of the diabase ridge forming the eastern side of the valley.

Again, on the left side of the Vaal River sand predominates, with the exception of a small area north of Riverton Road, again, to the south-west of Kimberley almost the whole of the area between the Vaal River and the Orange River Colony boundary is spread with a thick mantle of reddish sand. These flats of sand support a long coarse grass, while in many places large thorn trees flourish, but throughout this area the country has been greatly denuded of its arboreal vegetation.

On the Native Reserve, between Pudimoe and Taungs Stations, there are wide stretches of mealie-fields, showing that much of this red sandy soil has a considerable value from an agricultural standpoint.

Bare tracts of sand and sand dunes are rare, and are confined to the angles formed by the meeting of two rivers, *e.g.*, the junction of Harts, Riet, Vaal, and Orange Rivers.

The sand is often of a deep red colour, almost like brickdust, but upon approaching an area in which calcareous tufa predominates the colour is seldom so intense.

An examination of the material under the microscope shows that the grains are more or less rounded, especially those of quartz, and vary in diameter from a quarter to one millimeter in diameter. The red colour is due to a coating of oxide of iron, which is removed by boiling with hydrochloric acid.

The great bulk of the material is composed of quartz grains, which show trains of inclusions and cavities. Plagioclase felspar is not uncommon, and is present in the form of cleavage flakes, with the angles somewhat worn. Chalcedony and agate are rather rare; zircon and magnetite are abundant, while epidote is a common constituent.

The composition of the sand shows that it has not been derived from the disintegration of the rocks of the district alone. The felspar and magnetite have been contributed by the disintegration of the dolerites, but considering the great area occupied by amygdaloidal diabase, it is most surprising that grains of chalcedony and agate are so rare. The Dwyka shales are too fine-grained to have contributed much, while sandstones are not sufficiently abundant to account for the enormous quantities of sand.

It seems most probable that the quartz-grains have been brought down from the Transvaal by the Harts and Vaal Rivers, and from the Orange River Colony, Cape Colony, and Basutoland by the Orange River.

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The sand being deposited along the river banks, will be blown out over the country by the prevailing north-westerly wind. The decomposition of the diabase and dolerite and of the pyrites in the shales yield compounds of iron, which can be taken into solution and deposited as oxide in the cracks and cleavages of the sand grains and around the grains themselves.

A most remarkable phenomenon is the strong bleaching effect which pans have on the colour of the sand. For example, at the salt-pan of Herbert great quantities of bright red sand are blown into the pan from the north-west. In a very short time this sand is bleached, and ultimately it is blown out of the pan and is piled up as a dune of drab-coloured sand on its south-east side.

The sand grains have lost their coating of iron oxide and acquired one of carbonate of lime instead; the magnetite remains unchanged. The bleaching cannot be due to the action of organic acids, for the pans always contain an abundance of carbonate of lime. The sand loses a portion only of its colour in pans which hold fresh-water; the action does not seem to be so complete as in salt-pans, and this makes it very probable that the bleaching is dependant upon a small amount of salt in the water. The presence of a small amount of organic matter may also assist in the removal of the oxide of iron.

In places this covering of red sand attains a thickness of over 10 feet, but its depth is very variable, and it is usually underlain by calcareous tufa.

(2) *Calcareous tufa.*—This material commonly forms beneath the red sand, and wherever the covering is thin it crops out in a series of little hard knobs of most irregular shape. It covers wide areas of the glacial deposits and shales, and its presence at the surface is most frequently an indication of the existence of the Dwyka series below ground. Sometimes it overlies decomposed dolerite, more rarely the Pniel diabase, and it is abundant both on the plateau of the Kaap and on the flats at the foot of the escarpment.

Leaving out of consideration the area west of the Harts-Vaal River, we find that the tufa has almost invariably been formed by the rising to the surface of water charged with carbonate and the deposition of the dissolved matter consequent upon evaporation. The carbonates have been derived from the underlying formations. The Dwyka boulder-beds and shales are invariably calcareous, and, as we have seen, contain thin limestones and calcareous concretions; the dolerites also upon decomposition furnish a large amount of carbonate.

After rain the moisture is drawn to the surface, and the dissolved material deposited either as a layer or in irregular masses in the cracks and fissures of the rocks at the surface. In the case of the shales the joints form channels for the ascent of the

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solution, and carbonates are deposited both along these joints and along the planes of bedding (see Fig. 5). The volume of the rock is increased, and the shales are buckled up and contorted at the surface; deeper down the beds are undisturbed. In time the whole of the surface layer of shale has been permeated with calcareous material and increased in volume, and a thick bed of tufa results; upon close examination small fragments of shale are almost sure to be discovered. The same is the case with the Dwyka boulder-beds; the rock is broken up by veins of carbonate, and finally a bed of tufa is formed in which lie boulders derived from the disintegrated glacial material. This explains the large areas of calcareous tufa, the surface of which is strewn with boulders, sometimes striated, and often foreign to the district.

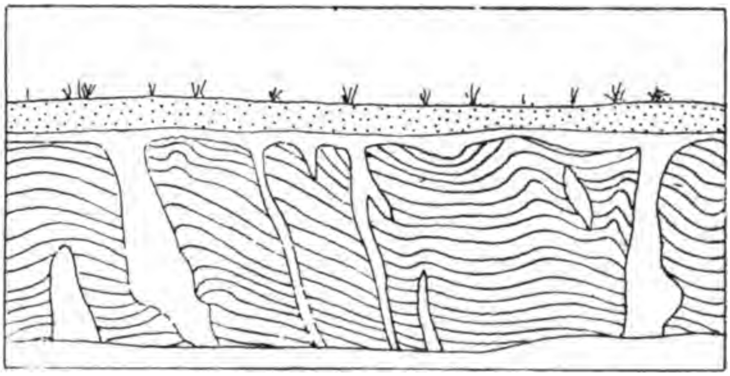

FIG. 5.—Showing the fissuring and contortion of shales through the formation of veins of calcareous tufa when a layer of the latter is produced below the thin covering of red sand. Length of section 12 feet. On railway half a mile north of Kimberley Station.

From Fig. 5 it is seen that the carbonate is brought up to the surface and deposited in the form of a more or less continuous bed below a layer of red sand.

With a thin covering of sand the bed of tufa grows at a nearly constant rate, and acquires a uniform thickness. It is thus forced to raise the layer of sand above it during its growth.

When the depth of sand is more than a few feet there is a differential growth of the tufa (see Figs. 6 and 7). Consider any single upward projection of the surface of the tufa. This is nearer the surface of the ground, and in consequence the capillary attraction will be so much greater. As a result, a larger amount of moisture will be evaporated from the surface of this little protuberance, and it will tend to grow at a greater rate than the rest of the deposit. It grows upwards and outwards, with an outline sometimes resembling that of a mushroom. Its

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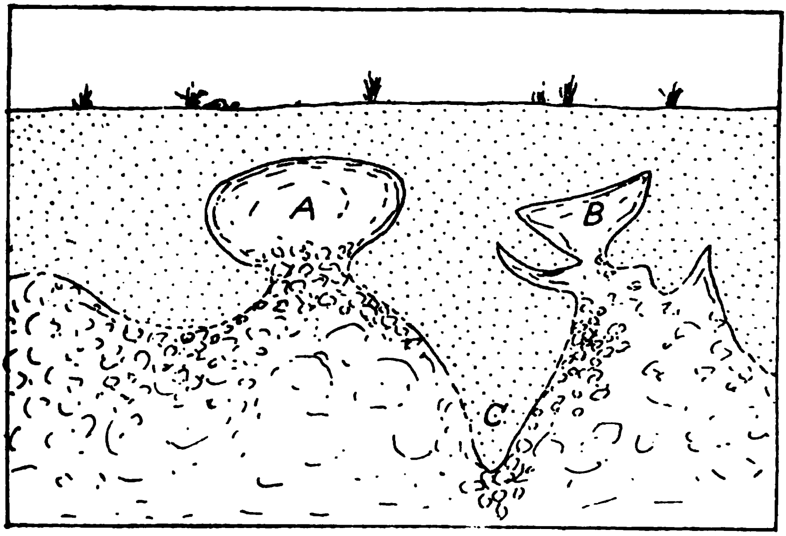

FIG. 6.—Showing the formation and differential growth of calcareous tufa below a thick cover of red sand. Length of section 10 feet. Cutting at the Phœnix Mine, north of Kimberley.

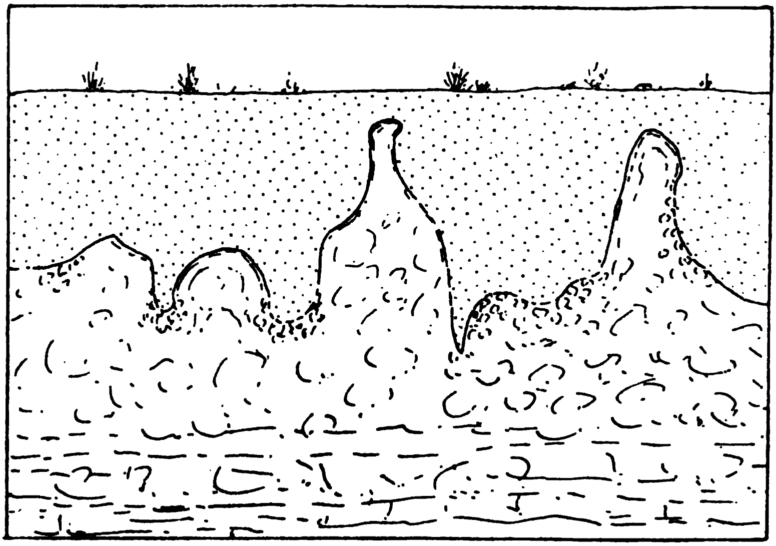

FIG. 7.—Showing the formation and differential growth of calcareous tufa below deep red sand. The tufa passes downwards into a rudely stratified deposit. Length of section 15 feet. Cutting at the Phœnix Mine.

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upper surface becomes hard, and upon being fractured the rock shows a somewhat banded structure, with flesh-coloured siliceous zones, and includes numerous little quartz grains. The base of such a hard growth is formed of more or less detached lumps of carbonate, but further down these lumps are bound together and the rock becomes more massive; ultimately it passes into normal rudely stratified tufa.

During the formation of the tufa most of the overlying material is pushed out, and the tufa envelopes only quartz-grains and small pebbles. At Klipdam, where tufa forms below the gravels in such places where the latter overlie the Dwyka formation, the limestone pushes out the earth and retains the pebbles. Sometimes pockets of earth and gravels are found in the tufa, but this is caused by the enlargement of two or more mushroom-like masses and their ultimate union. The initiation of such a process is seen in Fig. 6, and finally the contents of the hollow at C will be enveloped by the continued growth of A and B.

The tufa commonly has a thickness of from 5 to 20 feet, but at Pokwani Station a well 80 feet deep had not reached the solid rock. In a borehole at the same place sandstone was struck at 78 feet. The section showed two layers of tufa 30 feet and 32 feet thick respectively, separated by 10 feet of gravel. These deposits occur immediately opposite a kloof in the ridge to the east, and this probably explains their abnormal thickness.

Another variety of tufa is that which is found overlying the decomposed yellow ground of the diamondiferous pipes and fissures. It has a peculiar greenish-grey appearance, rather difficult to describe, but unmistakeable after having once been seen. The colour is due to small fragments of olivine, enstatite, etc., converted into a yellowish green serpentine. Occasionally the rock has a peculiar scoriaceous appearance, very much like that of a trachytic lava. The tufa passes downwards into the decomposing yellow-ground. Analyses of this variety of tufa are given by Cohen,* and these show that it contains a small amount of magnesium carbonate and a good deal of material insoluble in acid. Cohen† believed that the tufa had been deposited from brackish water during a depression in the Pleistocene Period, but there can be no doubt that Moulle and others were right in considering the material to have been formed in the same way as the tufa elsewhere, the calcareous matter having been derived from the decomposition of the yellow-ground.

On the plateau of the Kaap the rocks are hidden over wide distances by tufa, most of which has been derived by solution from the underlying limestones and dolomites. The thick deposits along the shallow stream-courses indicate that a certain amount of calcareous matter has also been brought down by running water.

* Cohen. Neues. Jahrb. f. Min., etc., 1887, p. 270.
† *Ibid.* p. 271.

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At Boetsap the Dwyka shales abut against the limestones of the Kaap, and the two formations are cut flat and are capped by a continuous sheet of tufa from 20 to 30 feet in thickness. This is the only locality along the edge of the Kaap where the shales rise high enough to form the easterly extension of the Plateau..

A small outlier of shales capped with tufa constitutes the "Fossil Hill," about 100 yards from the main road to Boetsap. The tufa here includes thin, impersistent, and more or less horizontal bands of fibrous stalagmite, in which lie fragments of bone. Many years ago the skeleton of a large animal was found at this spot, but nearly all the bones have been taken away by visitors.

Along the edge of the Kaap there are many springs, which bring to the surface large quantities of calcareous matter. In this way big, irregular masses of tufa have formed high up on the cliffs, while the slope extending eastwards towards the river are covered with a thick deposit, crowded with fragments of limestone, dolomite, flagstone, chert, shale, etc. This slope supports a thick growth of thorn-bushes.

Mr. Young‡ has given analyses of tufa from this belt of country.

The numerous little springs which issue at the base of the escarpment are probably due to the abutting of the less permeable Dwyka shales against a face of water-bearing dolomite. The water issuing disappears again within a short distance into the porous tufa, and there can be no doubt that the underground water resources of the Harts-Vaal River valley must be considerable.

Large springs issue from the dolomite, the water being brought to the surface by layers of hard impervious shale and flagstone. A splendid example of this is the spring known as Thabaseek, to the south-west of Taungs Station.

Terraces covered with calcareous tufa are found on the lower portion of the Riet River and on the Orange River at Hopetown; these represent plains of river erosion. The former is well seen on the farms Abraham Moos Fontein and Taaibosch Fontein, and has an altitude of from 70 to 120 feet above the river bed. The terrace at Hopetown is finely developed, and the tufa is about 30 feet thick. At the town it is 140 feet above the level of the river, and away from it it rises with a slope of about one in a hundred.

The tufa in each case is crowded with water-worn pebbles.

(3) *Pan-deposits.*—The floors of pans are formed by a reddish or greyish-black friable soil, sometimes rather argillaceous in character. Round the edges of pans there is not uncommonly a deposit of tufa, which contains remains of mollusca, *e.g.*, *Pupa*, *Succinea*, etc.

‡ Trans. Geol. Soc. S. A., Vol. IX., p. 58, 1906.

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At Roode Pan (Hayfield) there is a deposit of *diatomite* with a thickness of at least several feet. This material is probably not uncommon around pans, but is so easily mistaken for tufa.

(4) *Alluvium.*—Tracts occupied by alluvium are not very extensive. At Douglas there is a considerable area, which is irrigated from the Vaal River by means of a furrow. At the junction with the Riet and Vaal Rivers a large tract has also been put under irrigation.

At the junction of the Riet and Modder Rivers there is a wide alluvial flat, triangular in area, but unfortunately its agricultural possibilities have not been developed.

The big bends of the Harts, Riet, and Vaal Rivers enclose wide tracts of fertile land, of which up to the present but little use has been made.

IX. ON PANS.

Pans are very numerous in this area, and several are of large size, yet this is but the western side of that belt of country dotted with pans which extends along the western border of the Orange River Colony.

In this area the great majority of the pans have been produced by the stripping off of a covering of Dwyka conglomerate or shale from an uneven surface of diabase; in some cases the shales only have been removed, the conglomerate being so much harder, and conforming in outline to the underlying floor. In all cases the excavation has been accomplished principally by the action of the prevailing north-westerly and westerly winds.

As examples of pans determined by a simple hummock of diabase on one side we have Tweeling and Kokuming pans along the Transvaal border, east of Pokwani; that on Langleg, south-east of Riverton; Rust-en-Vrede and Grass Pan, west of Kimberley. As examples in which the pan is almost surrounded by diabase may be cited that on Zoutpans Fontein, near Riverton Road, and the pan 6 miles north-east of that station. All the large pans of Kimberley and Herbert have been formed in shales, below which the diabase forms a depression or basin. Thus we have the Rooi Pan (2 miles across), Vogelstruis Pan, Brak Pan, the pans at Paarde Berg East and Theron's mine, in the western part of Kimberley, and Rooi Pan (Craigie-Burn), Saltpan, Roode Pan (Hayfield), in Herbert. Other pans are surrounded by shales, and the diabase is not exposed in their vicinity, *e.g.*, pan north of Kimberley, Alexandersfontein, Klokfontein, Sluitels Dam, etc.

In a few cases erosion has cut through a thin horizontal capping of dolerite and exposed the softer shales below, thus producing a pan, as, for example, on the farm Brechin, north-east of Hopetown. The complete removal of the rim of dolerite will leave a pan in a flat of shale, and this probably represents the

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mode of formation of most of the pans situated upon shale flats bounded by dolerite hills. Such pans are located upon the Dwyka and Ecca shales.

As examples may be cited the pan on Leinster, north-east of Hopetown; Graspan, near the station of that name; Vaal Pan, south-west of Kimberley. It is very probable that the pans north of Kimberley, Alexandersfontein, etc. are of similar origin. Pans located upon dolerite are not common; there is one good example about 5 miles south of Warrenton, while another is Klip Pan (Burgher's Pan, according to Stow), near Graspan Station; a third is Dutoitspan. Sometimes a pan is located on the junction of shale with an inclined sheet of dolerite.

Swinks Pan, north-east of Belmont, is enclosed by a chain of dolerite hills produced by a sheet of dolerite dipping in all directions away from the pan. Denudation of the crown of this dolerite dome has exposed the shales and determined the position of the pan.

Production of pans by wind erosion.—As an excellent example we may take the Herbert Saltpan, of which a plan is given in Fig. 8; it has also been briefly described by Stow.† The depression is from 20 to 25 feet in depth, and nearly a mile in diameter; on the north and west the rim is very steep, while on the south and east are two curved lines of sand dunes. The red sand, which is blown in on the north and west, is rapidly bleached and ejected on the south and west, together with a certain amount of finely divided calcareous material. The loose sand forming the sand dunes is fixed by short grasses; deeper down it becomes compacted through the infiltration of calcareous material.

Similar sand hills are found on the east side of Roode Pan (Hayfield), but there are no clearly defined dunes. The large pan about midway between Kimberley and the pumping-station at Riverton has hills of loose sand on its south-east side.

At Klip Pan, where the pan is excavated in decomposed friable dolerite, the ridge to the east is formed of an accumulation of tiny fragments of dolerite cemented by tufa.

Owing to the deep sandy soil around most pans, very little material, and that only the finest sand, is carried down into the depression even during heavy rains. The pan soon dries up and the thin film of mud breaks up at first into fragments and afterwards into fine dust, which is readily removed by the action of the wind. Many pans are thus being deepened at the present day, but there is good reason to believe that certain pans are being silted up. This may be due either to the invasion of the

† G. W. Stow. Quart. Journ. Geol. Soc., Vol. XXX., p. 589, 1873.

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area by large quantities of drift sand or to the disturbance brought about by human occupation. Roads and ditches cut in the sides of the pan enable streams to discharge a large amount of sediment into the pan and thus silt it up. I was informed that many years ago the Herbert Saltpan had a fringe of tall reeds and grasses, while the country round about was thickly grassed; thus the discharge of sediment-laden water into the pan was to a great degree prevented.

Salt pans.—Owing to the influx of water into pans and its ultimate evaporation, there is always the tendency for pans to become salt.

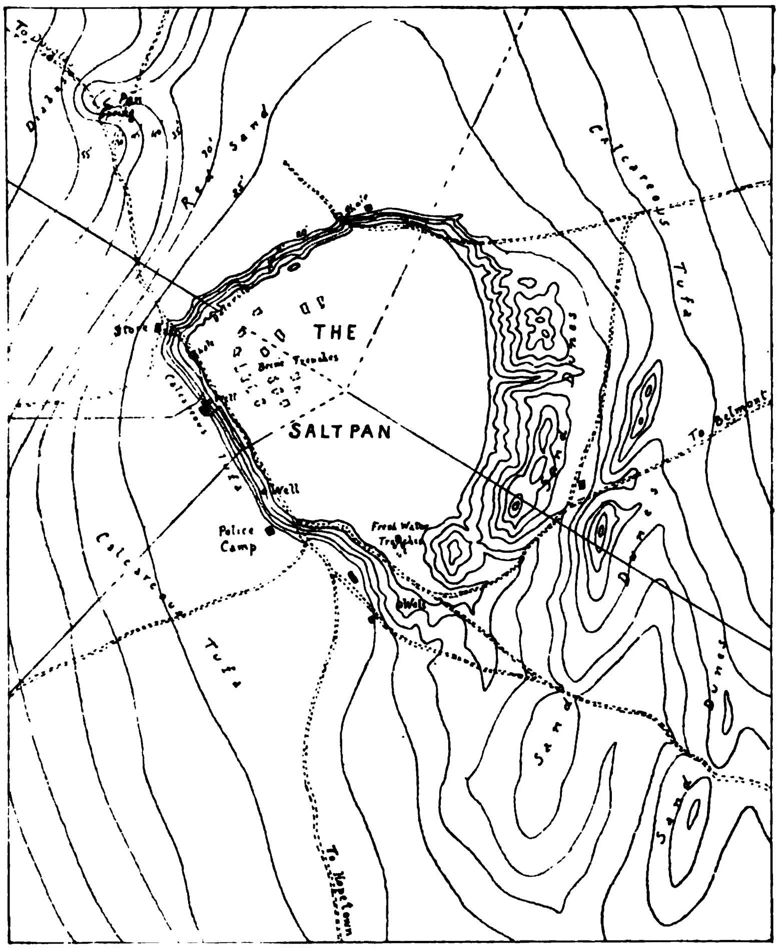

FIG. 8—Plan of the Herbert Salt Pan. Contour lines at intervals of five feet.

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At Theron's Mine the water from the pan contains, I am told, a certain amount of sodic nitrate, but all the other "brack-pans" yield common salt only; gypsum appears to be absent.

There are several pans in which the amount of saline matter is sufficient to justify its recovery. Thus, we have salt-works at Riverton Road, Klokfontein, and the Herbert Saltpan, while the Jacobsdal Saltpan is just across the border, close to Honeynest Kloof Station.

Wells and boreholes sunk in the Dwyka formation in the north and west of the Colony frequently yield salt water. The saline constituents are not disseminated evenly through the rocks, and it not uncommonly happens that of two wells a short distance apart, one produces fresh water while the other yields brine. As an example may be cited a small basin filled in with shales, a little to the east of the Leicester Mine. A well here produced brine, while, not 200 feet away, an enormous supply of fresh water is obtained and utilised in washing the diamondiferous gravels.

Seeing that many pans have been eroded out of shales, and are underlain by a basin-shaped surface of hard impervious diabase, it is probable that water in gravitating towards this depression, has leached out the saline matter in the Dwyka conglomerate and shale, and concentrated it below the floor of the pan. There will thus be produced in the soil a lower denser layer of brine and an upper lighter stratum of fresh water. The demarcation between the two liquids is probably sharp, for after rains the fresh water in pans is found to float above the brine without mixing for a certain period, and the supply of strong brine is not appreciably interfered with by a moderate rainfall.

This will explain why, at the Saltpan, fresh water is obtained from shallow pits round the sides of the pan and even on the gently sloping floor of the pan itself at its southern end.

The amount of salt stored up in these pans and available in the future must be extremely great, and therefore of no small economic importance.

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SECTION II.

THE DIAMONDIFEROUS AND ALLIED PIPES AND FISSURES.

I. INTRODUCTORY.

Pipes and fissures filled with the peculiar ultrabasic breccia, appropriately termed *Kimberlite* by Prof. Carvill Lewis, are numerous in the Divisions of Kimberley and Barkly West, and from the additions to their number annually it cannot be doubted that many still await discovery.

Of those which have been located and prospected only a small percentage have proved worthy of exploitation; the remainder may be termed "blank mines." Several of the mines abandoned some years ago are at the present moment being reopened and tested in a more systematic and thorough way. This is in part due to the improvements effected in the treatment of the material, whereby the cost of recovery of the gems is reduced, and in part to the higher prices realised for diamonds during the last few years.

The unique phenomena of the diamond pipes have attracted the attention of mining engineers and geologists from the date of their discovery in 1870, and the interest in them has by no means diminished with time and increased knowledge.

The great bulk of the literature on the subject deals principally with the mines of the Kimberley group, while not much has been written about the outside productive mines, and almost nothing regarding the numerous barren or unremunerative pipes and fissures.

In the succeeding account of the pipes it will, therefore, be unnecessary to give much detail regarding the mines of the Kimberley group, and description will be limited to such points as have been omitted in previous writings or about which there was some degree of uncertainty. This will be followed by a short discussion of pipes and fissures in general, and by a petrological description of material collected from the Kimberlite occurrences.

The following are some of the more important works dealing with the pipes and their contents from a general standpoint; other papers concerning the minerals and rocks associated with them will be referred to later on, while a full list of the literature is given in Miss Wilman's "Catalogue of Books and Papers on South African Geology."*

* Trans. S. A. Phil. Soc., Vol. XV., part 5, 1905.

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II. DESCRIPTION OF THE PIPES AND FISSURES.

A. DIVISION OF KIMBERLEY.

The Kimberley group consists of eleven pipes arranged according to the plan given in Fig. 9. Several other occurrences of Kimberlite were known in the early days of Kimberley, but the ground on which they occur has been either built over or reserved and almost all knowledge of their positions lost.

Kimberley Mine.—The workings in this mine have attained a depth of over 2,900 feet, and prove that from a depth of 800 feet downwards the cross-sectional area becomes nearly constant.

In section it is oval (Fig. 10*); at a considerable depth a fissure is found to extend westwards from the pipe, and has been followed several hundred yards without terminating; its width varies from 6 to 8 feet.

Taken in conjunction with the fact that the pipe inclines bodily towards the north it is very probable that this offshoot joins up with the St. Augustine's Mine.

Among the inclusions in the "blue-ground" of this mine must be specially mentioned dark quartzites, which, in spite of their bedded nature, are remarkably smoothed and rounded. Peridotites must be extremely rare, for after a prolonged search I obtained only one specimen.

De Beers Mine.—A plan of this mine is given in Fig. 11, and indicates possibly a twin-pipe, more especially as the north-western half contains such poor ground that this portion of the mine has not been found to be worth working. Some of this ground is a hardibank.

* Figs. 10 and 11 are taken from the Annual Report of the Inspector of Mines for 1892.

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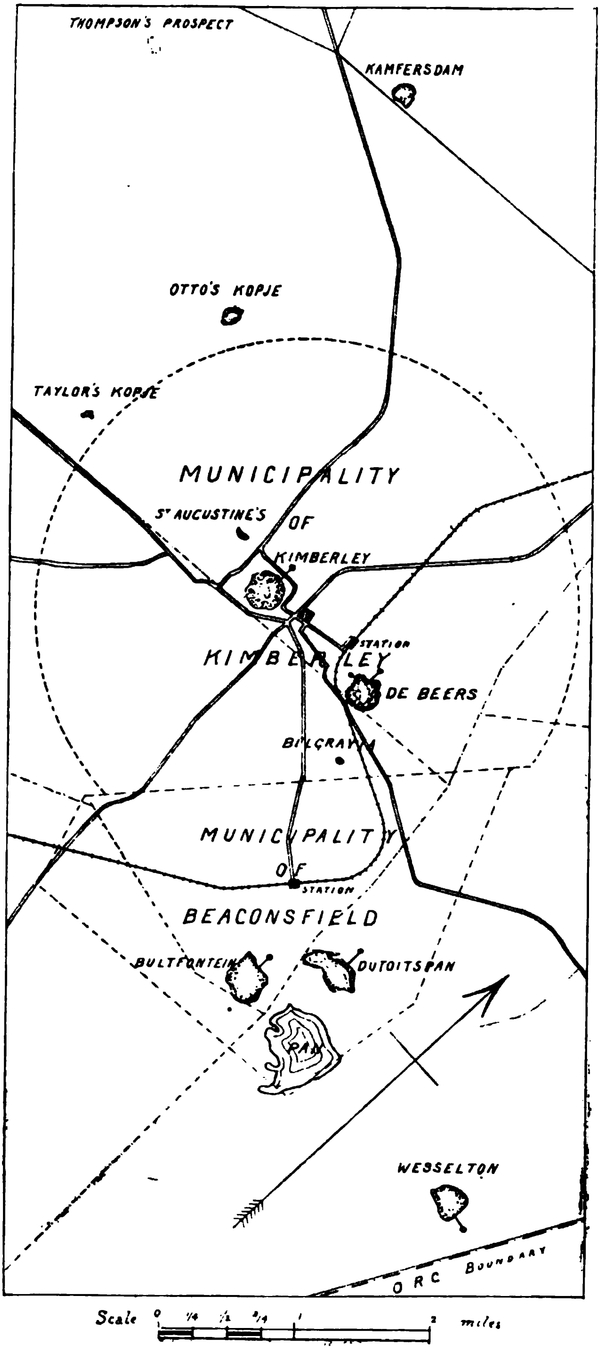


FIG. 9.—Plan showing the positions of the pipes in the neighbourhood of Kimberley.

Fig. 10 PLAN OF KIMBERLEY MINE

1000 FT LEVEL

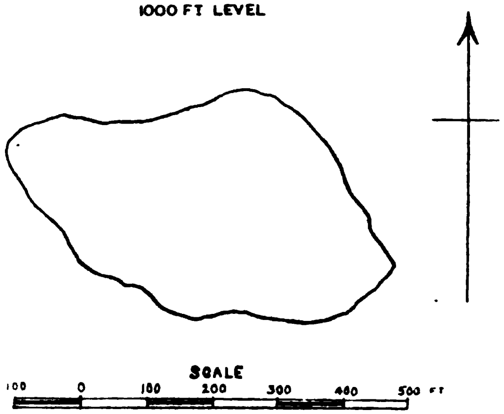
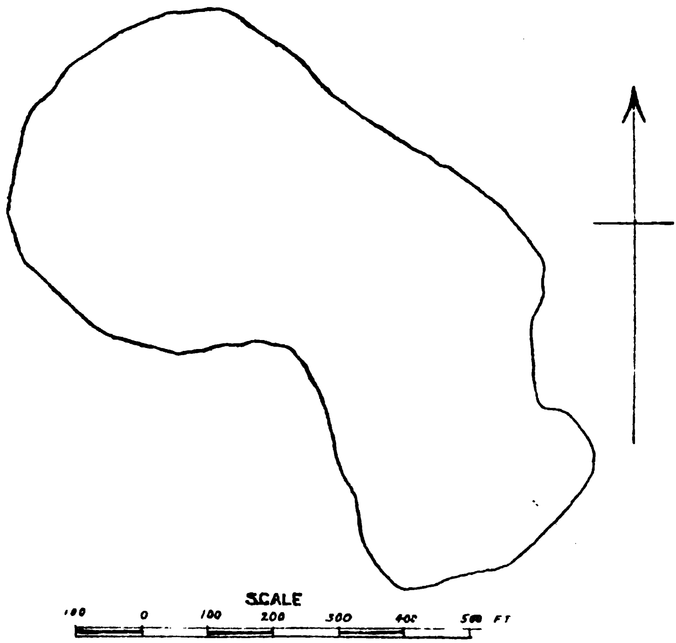


Fig. 11 PLAN OF DE BEERS MINE

800 FT LEVEL



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Considerable interest is attached to certain crooked dykes which traversed the yellow ground, whence the term "snake rock." The dyke rock is sharply defined from the yellow and blue ground, and cuts through the quartz-porphyry at the 1,720 foot level.

Inclusions of actinolite-schist and amphibolite are rather common in this mine.

Dutoitspan.—This mine is elongated with a constriction almost cutting off its western extremity. Much of the yellow ground is crowded with large boulders of dolerite, sandstone, shale, etc, and is often too poor to repay working. At the western end a big mass of hardibank forms a pyramid known as Mount Ararat. At the opposite end of the mine, there is a large dyke-like mass of brecciated dolerite.

The sandstone inclusions cannot be matched in the Dwyka series, and must have been derived from a higher horizon.

Boulders of coarse-grained peridotite are abundant in the blue-ground. Some of the hard blue is very fine-grained, devoid of foreign inclusions, and shows a beautifully vesicular structure, the vesicles being lined with small crystals of calcite.

Bultfontein.—A large area towards the north-west has been left untouched, being too poor to work. Some of this material shows distinct stratification, the bedding planes dipping at a high angle towards the centre of the pipe. On the south side and adhering to the wall of the pipe, there is a great mass of shale-breccia at least 100 feet in thickness, but which does not extend into the lower workings. In it is a block of whitish grey sandstone over 8 feet in diameter, and showing grooves and scratches on its exterior. Portions of the shale are similarly striated. Both the shale and sandstone are not represented among the sediments forming the wall of the pipe.

The most prominent feature in the Bultfontein Mine is a huge mass of brecciated dolerite, passing into a dolerite-shale-breccia, which extends across the pipe from north to south and dips nearly vertically.

Apophyllite and other zeolites have formed in beautiful crystals in the spaces betwen the masses of dolerite, and are accompanied by calcite.

The inclusions in the blue ground are very numerous, and the peridotites are frequently extremely coarse-grained rocks.

Wesselton (Premier) Mine.—This mine is of interest on account of the inclusions which have been found in the blue-ground.

A block of sandstone containing remains of a fossil fish was obtained at a depth of 135 feet. This was determined by Dr. A. Smith Woodward, of the British Museum, as an *Acrolepis*, a genus known as yet from the Beaufort beds only.

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At a depth of 220 feet a large mass of coal was discovered, and the five tons which were taken out were utilised in steam-raising at the mine, the coal proving to be of good quality.

There can be no doubt that both the fossil fish and the coal have been derived from higher strata, which at one time extended over this area and which have since been removed by denudation.

A portion of a carbonised tree trunk was unearthed at a depth of 350 feet, and may possibly have come from the same horizon as the coal.

St. Augustine's Mine.—This mine is situated a short distance to the west of the Kimberley Mine, about 150 yards from Tucker Street.

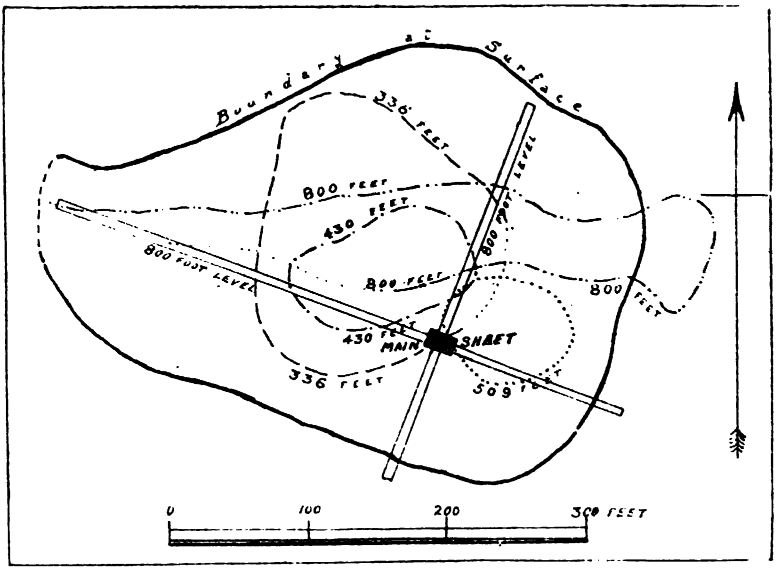

Fig. 12.—Plan of the St. Augustine's Mine, Kimberley, showing the boundaries of the pipe at the different levels.

At the time of my visit the mine was being filled up with debris, and in a short time no trace of its existence will remain.

A shaft was sunk to a depth of 820 feet, and a plan showing the boundary of the pipe at different levels is given in Fig. 12. Upon examining this it will be seen that the pipe varies considerably, not only in shape but in position as the depth increases, and at the 800 foot level it becomes elongated and fissure-like, the whole body of blue dipping northwards at an angle of about 45°.

At the surface the pipe is surrounded by black shales, which dip away on all sides at a considerable angle. At 800 feet the drives were in the hard quartzite of the Pniel series, the quartzite being struck at a depth of 751 feet.

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Nearly all the yellow ground was worked out, and many small diamonds recovered, but the hard-blue was met at a depth of 70 feet, and would not weather upon exposure.

The hard blue of the St. Augustine's Mine is quite unique, and is distinct from that of any other occurrence known to me. It is extremely hard and of a slatey blue colour; the mineral constituents are much larger than usual, attaining a size of an inch across occasionally. These mineral grains are nearly all smoothed and rounded as though water-worn, and often the rock has the appearance either of a conglomerate or of a lava with infilled vesicles.

The grains are not always regular in outline, but they very rarely show any faces and sharp edges; the surfaces are always dull and dark coloured, and they appear rough under the microscope.

They range from less than one-eighth up to an inch in diameter. Olivine, ilmenite, and enstatite are abundant, garnet and diopside rather rare.

Inclusions within the pipe are not abundant, and consist chiefly of shale, quartzite-conglomerate (from the base of the Zoetlief beds), and diabase.

Kamfersdam Mine.—The pipe is situated about four miles to the north-west of Kimberley. The portion worked is nearly circular in outline, and is surrounded by shales. On the south-east side there are two dyke-like masses of hardibank. One of these crops out at the surface, and can be followed across the fence into the farm Vooruitzigt, where it has a width of about 30 yards. It is hard and brownish in colour at the surface, but below ground in a shaft it changes to dark green. It contains large decomposed olivines and is almost devoid of any foreign inclusions; it passes insensibly into normal yellow or blue ground.

To the south-east the hardibank is replaced by soft yellow ground, and forms an area at least 200 feet wide and 500 yards in length.

The pipe may, therefore, be regarded as rather elongated, with a constriction (filled with hardibank), while its north-western extremity is circular in outline.

The Kamfersdam pipe is interesting as showing the effect of heat upon the shales at the contact with the yellow ground. This is well seen at the north-western edge of the pipe. The shales have been tilted by the intrusive kimberlite and lenticular portions included by the latter, the shale being baked to a hard flinty material (lydianite). Fragments of similarly altered rock are included in the hardibank.

On the west side of the mine the shales dip towards the pipe, a marked exception to the general tilting away of the strata.

On the north side of the mine, at a short distance down, was a horizontally lying wedge-shaped mass of a peculiar breccia

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or pseudo-conglomerate. The rock composing it is light grey in colour, and consists of fragments of soft shaley mudstone set in a similar groundmass and containing neither yellow ground nor foreign boulders.

The fragments vary from angular to sub-angular; generally the corners and edges have been worn off and sometimes the faces are finely scratched and striated. The rock evidently represents a mass of brecciated and crushed shaly mudstone.

The blue ground is characterised by an abundance of fragments of black shales and well-rounded boulders of dolerite, usually so large as to require blasting before removal.

The diamonds won are said to be, as a rule, small and of inferior quality.

Otto's Kopje.—This mine is situated about two and a half miles to the north-west of Kimberley. After having been worked for some time the mine was closed down, but lately some development work has been undertaken, and there is some hope of it being re-opened.

In outline the pipe much resembles Kamfersdam. Thus the portion worked is rudely circular, or more correctly, somewhat elliptical. It exhibits a similar constriction and then expands into an elongated pipe, whose boundaries have not been exactly determined.

The longer axis of the pipe, unlike that of Kamfersdam, is directed towards the south-west.

The diamonds are said to be of good quality.

Taylor's Kopje lies a little to the south, almost in line with Kamfersdam and Otto's Kopje. This mine was abandoned many years ago. The blue ground is interesting petrologically, and the shale fragments show the action of heat very clearly.

There are several other abandoned mines in the neighbourhood of Kimberley, *e.g.*, the *Belgravia* within the town, and *Thompson's Prospect* north-west of Otto's Kopje. Moulle* notes also a pipe known as *Doyle's Kopje*, somewhere to the north of the Kimberley pipe, and probably included in the area covered by the "floors" attached to that mine. It was of interest on account of the large inclusions of granite which occurred in the ground.

North of Kimberley are several pipes which are not being worked at the present time, *e.g.*, the *Pole* and *Phœnix Mines*, between Dronfield and Riverton Road Stations, and also one on the farm Zoutpans Fontein, about half a mile from the Vaal River.

South of Kimberley, at Wimbledon Siding, are two oval-shaped pipes, one about 250 feet and the other about 300 feet in length. They are surrounded by dolerite, but the shale underlying is exposed in some of the inclines. The inclusions in the

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* A. Moulle, p. 73.

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yellow ground consist of granite and gneiss, amphibolite, gabbro, peridotite, diabase, dolerite, rhyolite, flagstones, shales, etc.

Theron's Mine or Kimberley West is situated on the farm Roode Pan, about $27\frac{1}{2}$ miles to the west-south-west of Kimberley.

The pipe is on the eastern side of the pan, and occupies quite a considerable portion of the pan itself; its exact boundaries in this direction have not been determined, and it appears to have an irregular outline. The country rock has been laid bare on the north side, and proves the pipe to be funnel-shaped. The strata dip away and the rock surface is smooth and shows vertical striations.

The most noticeable feature in this mine is the clear evidence which it shows of the high temperature of its contents at the instant of their intrusion. The soft Dwyka shales forming the walls of the pipe have been baked into a hard flinty material, and the gradual increase of metamorphism as the pipe is approached can be well studied in a long incline on the south-east side of the mine. The zone of alteration extends for a considerable distance and is quite as marked as in the case of many dolerite intrusions.

Large masses of "floating-reef" have been altered throughout; in many places the beds have been shattered and penetrated by numerous tongues and veins of kimberlite, and often the rock passes into a bluish breccia of great hardness.

The yellow-ground does not differ from that of any other mine, and is diamondiferous. Masses of dolerite are present, but the great bulk of the inclusions consist of hardened shale.

Paarde Berg East.—This mine, a few miles to the north-west of Theron's Mine, is in course of development, and its limits at the time of my visit were uncertain. This was in part owing to the great size of the inclusions ("floating-reef") in the yellow ground, requiring a large amount of work before their exact nature could be realised.

Some of these inclusions must have been broken from the sides of the pipe, and have suffered hardly any vertical or horizontal movement, for they are masses of Dwyka horizontally bedded passing downwards from shale into conglomerate and entirely isolated in the yellow ground. The base of the Dwyka formation cannot be deep, for a small hummock of diabase crops out between the mine and the homestead.

In the eastern workings the shales have been converted into hard flinty and quartzitic material.

Both in this and in Theron's Mine the calcareous tufa overlying and adjoining the pipe contains small fragments of ferruginous material, doubtless oxidised pieces of hardened shale.

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This is an indication of the proximity of a pipe in which the effect of heat is well marked.

Yellow ground has been located at several other points on this farm, but more work is needed to determine the extent and value of the occurrences.

On *Secretaris*, west of Kimberley, there are several fissures filled with kimberlite, and which trend in different directions; the westernmost one must have a considerable length. Eclogite boulders are common in the eastern fissure.

B. Division of Barkly West.

Immediately to the west of the town of Barkly are the *Russell* and *Victoria Mines*, and in the angle formed by the Vaal and Harts Rivers, the *Washington* and *Borrell's Kopje Mines*.

In the last named, the yellow ground is overlain by from 2 to 3 feet of hard conglomerate containing water-worn river pebbles and that in turn by from 15 to 25 feet of calcareous tufa.

The Newlands Mines.—An excellent description, accompanied by a plan of this group of pipes, has been given by Graichen*, supplementing the full account of the rocks and minerals by Bonney.†

The pipes occur on the farm Newlands (H.V. 42) on the left bank of the Harts River. Dwyka shales form the country rock, and are covered by a thin capping of Karroo dolerite.

The main shaft at No. 2 mine passed through dolerite, black shale, Dwyka conglomerate, "bastard-blue," and, at 250 feet, entered diabase (amygdaloidal, porphyritic, and brecciated), containing a bed of black quartzite, possibly the same bed as that interbedded in the diabases a little to the east of Delport's Hope. Blue ground was struck at 463 feet, and as the pipe opens to the surface at a distance of nearly a hundred feet to the north, it has apparently a deviation of over 10° from the vertical.

There are four small pipes arranged along a nearly straight line, the most interesting feature being their connection with one another below ground by means of a dyke of kimberlite, which varies in width from one up to seven feet. This dyke only rises to the surface in certain places, but its continuity below ground has been proved in the workings. Its strike is nearly north-east.

The blue ground is very hard, and contains numbers of garnets. Inclusions of granite, diabase, dolerite, and eclogite are common.

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* W. Graichen. Zeits. für prakt. Geol., Vol. XI., p. 448, 1903.

† T. G. Bonney. Geol. Magazine, p. 309, 1899

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The interest in the Newlands Mines centres in the discovery of small diamonds embedded in boulders of eclogite.‡

The diamonds recovered from the kimberlite, although small, were of a very high quality. The mines were abandoned owing to the hardness of the ground and the small workable body of material.

Smith-Weltevreden Mine.—Further up the Harts Valley in a depression between two dolerite capped ridges, is the pipe commonly known as the Frank Smith Mine.

As indicated in Fig. 13, this is really a twin pipe, the greater portion of which falls within the farm H.V. 37. The area on

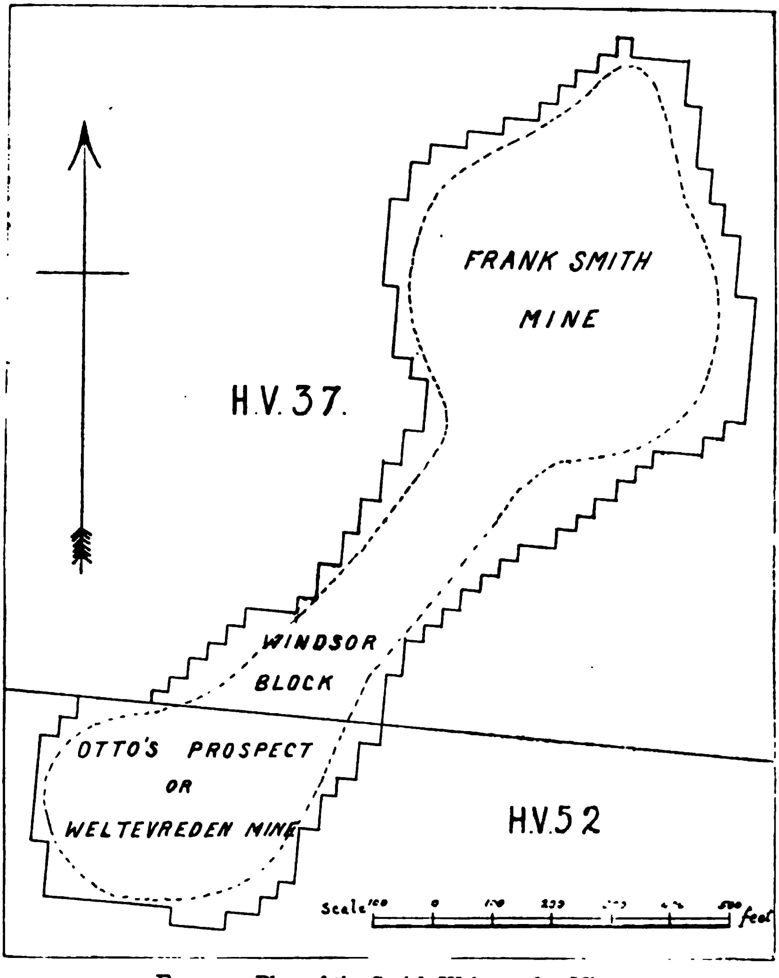

Fig. 13.—Plan of the Smith-Weltevreden Mine.

‡ See above papers, and also R. Beck., Zeits. für prakt. Geol. p. 163, 1898.

H.V. 54 has been worked separately, and is known as Otto's Prospect or the Weltevreden Mine. The narrow neck north of the fence is called the Windsor Block, and the remainder of the pipe, the only part which is being worked at present, is called the Smith Mine.

The neck uniting the two portions of this dumb-bell-shaped pipe enters very sharply into the northern area, and is not more than 150 feet in width. The material filling it is mostly a hardibank, and contains very little so-called yellow ground, nevertheless, curiously enough, this portion of the mine contains large lumps of ilmenite and is rich in diamonds.

Just on the line of the fence there is a large mass of breccia, composed chiefly of red and purple basaltic lavas, the amygdales being filled with calcite and zeolites. Lithologically they have a great resemblance to the Stormberg lavas of Cape Colony.

In thin section (1567-9) under the microscope the rocks prove to be olivine-basalts. The felspar (labradorite) is slightly altered, but the augite is quite fresh, and the two minerals mutually interfere.

Olivine is in small idiomorphic crystals altered sometimes to a brownish laminated or fibrous pleochroic mineral resembling iddingsite, but more usually to greenish serpentine. The groundmass consists of a dark brownish glass containing microlites and granules of iron ores. It is often rendered opaque through the presence of ferric oxide..

These fragments of lava have either fallen into the pipe from above or else have been derived from a mass of molten material in the pipe and which is either slightly earlier than or contemporaneous with the intrusion of the kimberlite.

With each of these views there are difficulties, and it is impossible to decide which is the more likely.

Sapphire and rubies were reported by Prof. Lawn from this mine, but it seems probable that there is some mistake in the identification, especially in view of the fact that fragments of a garnet-cyanite rock have been obtained from the blue-ground.

Leicester Mine.—This is situated on the farm Eland's Drift, a couple of miles to the south of Klipdam. It penetrates diabase, Dwyka conglomerate (the latter being about 3 feet thick) and shales. Being located in one of the basin-shaped hollows in the diabase the mine makes a great deal of water.

The Balmoral or Jubilee Mine, a small cylindrical pipe, penetrates diabase about three-quarters of a mile to the north-east of the Leicester.

Wrigley's Kopje is much larger, and is a short distance further on.

The diamonds from the Leicester, Balmoral, and Newlands Mines, and perhaps also Wrigley's Kopje, are said to be finer in quality than those of any other mine excepting Jagersfontein.

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Several small mines lie to the south of Klipdam, others to the north, *e.g.*, Cyrus Mine (H.V. 11). On Llanover (H.V. 61) there is a long fissure extending westwards on to H.V. 30, while several pipes have been located in the neighbourhood.

III. THE PHENOMENA OF THE PIPES AND FISSURES.

(1) *Distribution.*—In the earlier days it was generally believed that there was a well-defined narrow area—the "Diamond Belt"—to which the pipes were confined.

In 1896 we find Bauer, following Penning,* upholding the theory that all the mines from the Newlands to Jagersfontein are arranged at points along a nearly straight fissure,† while as late as 1903 we have an advocate of this view in Graichen,‡ in spite of the fact that the Newlands group of dykes and swellings which he describes extend almost at right angles to this direction. Every day shows more and more the erratic distribution of the occurrences of Kimberlite; pipes may occur in groups or be arranged along more or less straight lines, but considered as a whole, they show no regularity of distribution.

(2) *Shape and contour.*—Between the extremes of Kimberlite occurrences—*pipes and fissures*—there are all connecting links; those which, though dyke-like, expand at one or more points may for convenience be termed "*fissure-swellings.*"

Balmoral and Jagersfontein are examples of pipes with a more or less circular outline, but the great majority are oval or elongated; some have a small expansion at one end, *e.g.*, Dutoitspan and Otto's Kopje. Pipes such as these can often be regarded as having been produced by the coalescence of two or more distinct chimneys, and as a fine example of this may be cited the dumb-bell-shaped Smith-Weltevreden mine.

The section of every pipe shows variations in contour at different depths, and sometimes there are remarkable changes within comparatively short distances. For example, in the De Beers Mine a variation of one hundred feet horizontally has been known to take place within a vertical range of about twenty feet. The walls of most pipes show in consequence hollows and protuberances, which may affect in no small degree the area of workable ground.

A bodily deflection of the pipe is not uncommon, as previously mentioned; another good example is the Kaalfontein mine of the Transvaal.** As an extreme case we have the St. Augustine's mine at Kimberley. According to old plans, the pipes of the Kimberley group after emerging from the hard diabase ex-

* W. H. Penning. Gold and Diamonds, p. 6. 1901.
† M. Bauer. Precious Stones, p. 212.
‡ W. Graichen. Zeits. für prakt. Geol., p. 448, 1903.
** Kynaston and Hall. Rept. S. A. A. A. Sc. for 1903, p. 191.

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panded considerably, thus forming a funnel-shaped throat. Moulle || states that the sides of the Kimberley mine were inclined to the central axis at an angle of about 15°. This feature appears to be due, firstly, to the easier shattering and disintegration of the soft shales, and, secondly, to the rending action due to tne subsequent expansion of the altering Kimberlite.

Below the Karroo rocks the cross-sections diminish a little at first, and ultimately acquire a nearly constant area.

The intimate connection between pipes and fissures, so well seen in the St. Augustine's mine, receives ample confirmation from the study of other occurrences, and it may, I think, be put down almost as a generalisation, that every pipe has some important dyke-like off-shoot, if not at the surface, at some greater depth.

In the Newlands group the pipes are connected below ground by a narrow dyke of Kimberlite; on Secretaris, west of Kimberley, we have fissures with one or more little swellings on them, and thus finally we arrive at the numerous class of Kimberlite "dykes and veins," which vary in width from belts many feet across to mere stringers.

The direction of some of these fissures is often probably connected with the jointing in the hard rocks which they penetrate, *e.g.*, Newlands, Smith, and Peiser mines (Hay), which have a north-easterly strike parallel to that of the surrounding pre-Karroo formations.

(3) *Contents of the pipes and fissures.*—The inclusions found at any particular locality in a pipe may have been derived (*a*) from above, (*b*) from the sides of the pipe, or (*c*) from below.

(*a*) There can be no doubt that in times past the pipes extended upwards through strata higher than those which now exist in the neighbourhood. Mr. Harger¶ has laid special stress upon this point.

The evidences for this upward extension are drawn firstly from the inclusions within the pipes, and secondly from the great amount of denudation which has taken place in Central South Africa since Jurassic times.

The inclusions of the Wesselton mine afford convincing evidence, while in the Premier mine of the Transvaal†† there are great masses of Waterberg conglomerate, though the base of the latter formation is only seen *in situ* some miles away. Small fragments of Karroo shale have been carried down to great depths, and are an abundant constituent of the blue-ground in the lowest workings of the Kimberley mine, *i.e.*, over 2,000 feet below the base of the Karroo formation.

(*b*) Many of the large masses of "floating-reef" appear to have been broken from the walls of the pipe during a late stage

|| A. Moulle. p. 57.
¶ H. Harger. Trans. Geol. Soc. S. A., Vol. VIII., p. 113-5, 1905.
†† Kynaston and Hall. Rept. Geol. Surv. Transvaal for 1903, p. 44.

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in the eruption, and to have suffered but little vertical displacement. Such masses, sometimes entire, sometimes brecciated, were abundant in the upper funnel-shaped openings of the mines of the Kimberley group, and have been noticed as well in Paarde Berg East.

(*c*) The great bulk of the material filling the pipes has, of course, come up from below. For example, there are fragments of sedimentary and volcanic rocks from the pre-Karroo formations, granite gneiss and pegmatite, tremolite and actinolite schist and amphibolite. Among the rarer rocks are gabbro (Wimbledon), garnet-cyanite-rock (Frank Smith and Roberts Victor), and glaucophane rock (Peiser).

In the pipe at Silver Dam (Sutherland), which is allied to those at Kimberley, are granulites of various types related to the eclogites, while lastly we have the extremely varied holocrystalline basic and ultrabasic rocks, composed of different combinations of the minerals olivine, enstatite, chrome-diopside, garnet, mica, and sometimes ilmenite, and which have contributed largely to the formation of Kimberlite.

The most prominent feature in all the inclusions is the remarkable degree of rounding which they exhibit; it is therefore not surprising that Prof. Bonney‡‡ should have come to the conclusion that the eclogite boulders in the Newlands mine had been derived from true water-formed conglomerates. The dolerite boulders are commonly in large rounded masses; the ultrabasic inclusions sometimes attain a length of two feet, and show pitted surfaces owing to the decomposition of the crystals of olivine; the eclogites have invariably smooth, sometimes polished, surfaces. The blocks of quartzite have their corners worn off, and the only rocks which do not show the effects of attrition are the shales and fissile quartzites. Even the mineral fragments are frequently rounded, but some of this smoothing may be due to other causes.

There is abundant evidence to prove that there has been a great deal of oscillation of the eruptive material—"cup and ball action"—with consequent rounding of the rock inclusions.

In certain places the "blue-ground" is crowded with foreign fragments, and passes into the material commonly known as "bastard-blue." It does not differ essentially from ordinary blue, and may contain diamonds; more usually it refuses to weather, and forms a hardibank.

On the other hand, there are certain portions of the "blue-ground" which are remarkably free from inclusions; they are met with either as lumps or patches (the so-called "concretions"), as veins cutting the bluc, or as narrow dykes in the country rock.

(4) *Temperature of the eruptive material.*—There are two opinions generally held as to the temperature that existed in the

‡‡ T. G. Bonney. Geol. Mag., p. 320, 1899.

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pipes: one that the "blue" is the product of cold volcanic action, the other that the material was erupted in a highly heated condition.

Luzi's experiments* apparently establishing the corrosive action of molten "blue" on the diamond have been widely quoted as proving a low temperature for the formation of Kimberlite.

The experiments have little value in this connection, for the following reasons:—

(*a*) The blue-ground differs both chemically and mineralogically from the original eruptive matter.

(*b*) From the description of the experiments it is quite possible that the corrosion may have been due to oxygen contained in the melted rock.

(*c*) Even assuming that the molten blue can attack and dissolve the diamond, it certainly does not follow that the reverse process cannot take place.

The effects of high temperature are well seen in the Kimberley West and Paarde Berg East mines, and to a lesser degree in Kamfersdam. In most mines, however, the effects of metamorphism are by no means well recorded—nevertheless, fragments of shale frequently show signs of alteration. Under the microscope such fragments exhibit numerous pale yellow garnets of extremely small dimensions, accompanied by a biotite mica in minute flakes.

In hand specimens many inclusions show zoning to a greater or lesser degree; such changes may, however, be due in part to hydrothermal action.

The effect of heat is indicated by the occurrence of fire-damp in the blue-ground at its contact with the walls of the pipe,† due to the distillation of masses of black shale. The aromatic hydrocarbons extracted from the blue-ground by Sir H. Roscoe have evidently originated in the same way.

On the other hand, many mines exhibit no signs of the action of heat, *e.g.*, the Wesselton mine.

The evidence, apparently conflicting, can, I think, be reconciled by supposing that the Kimberlite magma, at one time in a highly heated state, became chilled during its ascent in the pipe, so that different mines might record the effects of the material at different stages in its cooling.

The Kimberlite dykes of the United States have produced considerable metamorphism both in the country rock and in the inclusions.‡

(5) *The Genesis of Kimberlite.*—It would be useless to discuss the numerous hypotheses to account for the formation of the diamondiferous blue-ground.

* W. Luzi. Ueber künstliche Corrosionsfiguren am Diamanten. Berichte der Deutschen Chemischen Gesellschaft XXV., p. 2470, 1892. Quoted by Gardner Williams.

† A. Moulle. p. 58.; also Ann. Rept. Inspector of Mines for 1895, p. 13.

‡ Carvill Lewis. Genesis and Matrix of the Diamond, pp. 60 and 63, 1897.

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The theory which, I venture to think, seems to accord best with the facts may be put briefly as follows:—*That Kimberlite has been produced by the shattering of various holo-crystalline basic and ultra-basic rocks and the incorporation of this material by a magma of ultra-basic character.* In its ascent the eruptive material has become cooled and brecciated, and has included in its body fragments of the rocks through which it has passed.

The minerals and mineral fragments in Kimberlite may be divided into three groups according to their source:—

(*a*) Tremolite, smaragdite†† (hornblende), epidote, orthite, tourmaline, rutile, muscovite and biotite mica, apatite, wollastonite (?), and zircon. These have evidently been derived from granite, gneiss, pegmatite, and actinolite schists, and probably also from inclusions in the granite.

Zircon is so abundant (*e.g.*, at the Kimberley mine and Smith mine) that it may possibly have been derived from certain of the basic or ultra-basic rocks.

(*b*) Olivine, enstatite, chrome-diopside, garnet, brown mica, occasionally ilmenite, magnetite and chromite, more rarely hornblende, spinel (picotite, pleonaste, etc.), sphene, cyanite, sapphire, graphite, and the diamond.

These minerals have probably been derived from the basic and ultra-basic holocrystalline rocks—rocks which are often well foliated, and exhibit mineral banding, and which both in hand specimens and under the microscope not infrequently show the effects of dynamic metamorphism. They vary in texture from medium to coarse-grained, and there are sometimes pegmatites. The coarser-grained the rock the more friable it is, and with the pegmatites the portions found are usually fragments of the constituent minerals.

These rocks are mostly deficient in alumina, and hence the rarity of cyanite and spinel.

Owing to the allotriomorphic structure of the parent rocks, the derived fragments in the blue-ground commonly possess angular outlines; the shattering of the material will account also for the frequent discovery of fractured diamonds. The garnets, on the other hand, having originally more or less rounded outlines, tend to break out entire, while the formation of kelyphite rims produces beautifully smooth garnets—"buckshot garnets."

The most noticeable feature in this list of minerals is the absence of perofskite and the very infrequent occurrence of iron ores.

(*c*) Olivine, diopside, enstatite (?), brown mica, magnetite, ilmenite, chromite (?), apatite, perofskite, nepheline, and melilite.

From the evidence set forth below it seems that these min-

†† The smaragdite of Maskelyne and Flight appears from its analysis to be a green actinolitic hornblende with a trace of chromic oxide; a similar amphibole has been recorded from certain diorites.

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erals can with a certain degree of probability be ascribed to a deep-seated eruptive magma—which crystallised during its ascent in the pipes, and incorporated in its mass the groups of minerals *a* and *b*.

The Kimberlite of Cape Colony is characterised by the presence of porphyritic olivines, a fact which led Carvill Lewis to term the rock a brecciated porphyritic peridotite. The olivines have very often beautifully regular crystal-outlines, sometimes they are perfectly round, at other times they exhibit corrosion cavities.

Some of this mineral in the blue must be derived from the holocrystalline series, for irregular fragments of olivine are found showing cataclastic structure (1532), or the olivine granules are interlocking (1533); they enclose enstatite (1501, 1508, 1555), or are themselves enclosed by diopside (1079, 1100).

Some of the enstatite can undoubtedly be referred to the holocrystalline series; fragments show intergrowths with diopside (1100, 1518), or include biotite (1501), and sometimes they exexhibit strain shadows. Occasionally the mineral passes into a bronzite, and carries abundant minute platy inclusions of ferric oxide. A small amount of the enstatite possesses idiomorphic outlines, and may therefore be one of the minerals which has separated from the magma.

Diopside is not uncommonly idiomorphic (especially in slide 1077), and judging from the abundance of this mineral in some varieties of Kimberlite, it must in great part have been derived from the magma. The diopside of the holocrystalline rocks has usually a greener tint; some of the chromiferous varieties are feebly pleochroic.

Ilmenite and magnetite are abundant, and perhaps indicate the deep-seated origin of the magma. The blue-ground is crowded with little crystals of perofskite, which frequently show cores of ilmenite and sometimes, though less commonly, of sphene; not infrequently grains of ilmenite are surrounded by a shell of a colourless, highly refracting and weakly polarising material, which seems to be also perofskite. The great bulk of the perofskite may therefore have arisen by the alteration of the titanic iron, as suggested by Carvill Lewis. Some of the ilmenite contains about 12 per cent. of magnesia.†

Nepheline has as yet only been recognised in some Kimberlite from the Monastery mine in the Orange River Colony.‡

Melilite has been found in the melilite-basalt of Sutherland†† in pipes which contain the same assemblage of rocks and minerals as the Kimberley ones. Carvill Lewis suggested that melilite was possibly present originally in the groundmass of Kimberlite, though now altered beyond recognition.

† E. Cohen. Neues Jahrbuch, 695, 1877. Stuttgart.
‡ A. Lacroix. Bull. Soc. Minér., Vol. XXI., p. 22, 1898. Paris.
†† Ann. Rep. Geol. Comm. for 1903, p. 43.

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A study of sections (1501, 1077, 1548) of the purer varieties of Kimberlite convinces me that the original uprising igneous material may be classed as a *limburgite.* These purer portions range from large lumps down to fragments of microscopic dimensions, and are embedded in the brecciated and tuff-like masses of the pipes.

In the limburgite of slide 1077 the glassy base has been replaced by serpentine, but in 1548 there remains colourless isotropic material after treatment with strong acids. Although basic or ultra-basic glass would in most cases be altered to serpentine, its existence in the melilite-basalts and glassy vesicular lavas of the Sutherland Commonage pipes shows that such a change does not always take place. In support of this we sometimes find enclosures of brown glass in the olivine phenocrysts. The limburgite of slide 1077 has a very strong resemblance to melilite-basalt, especially through the presence of abundant perofskite and of mica. It is to be regretted that no analysis has been made of this rock.

In the breaking-up of the partially crystallised magma during the formation of Kimberlite the crystals derived from the former and now embedded in the blue-ground not infrequently still show an adhering film of the groundmass in which they originally crystallised (1501, 1099). The same thing has been noticed in a specimen from one of the melilite-basalt pipes.

It is of interest in advancing this theory to find an almost exact parallel from a pipe in Bohemia.|| The pipe is filled with a basaltic breccia containing fragments of various rocks which have been brought up from below. From this tuff almost every one of the minerals characteristic of Kimberlite have been obtained, some of which are derived from the basalt and the remainder from granite, granulite, gneiss, schists, lherzolite, and other inclusions.

Assuming that a highly-heated magma has incorporated in itself fragments of holocrystalline rocks, it would at first sight be expected that there ought to have been a considerable amount of reaction between the magma and the inclusions. Roozeboom¶ has, however, shown that at great depths, such as those at which we may suppose the holocrystalline rocks to be situated, the solubility of silicates is very much less than under normal pressures. Again, Zirkel** has found that at low temperatures basic inclusions are not dissolved by a basic magma. Moreover, olivine has been proved to be scarcely acted upon by basic magmas generally.

In consequence it will follow that the reactions in any case would be slight; in addition, both the magma and the inclusions

|| I. H. Oemichen. Zeits. für prakt. Geol., p. 10, 1900.
¶ C. Doelter. Petrogenesis, p. 121, 1906.
** F. Zirkel. Petrographie, Vol. I., p. 600, 1893.

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possess almost the same basicity, and thus there might be practically no interaction.

Thin rims of brown mica sometimes wholly or partially surround some of the minerals, especially the garnet, but as this feature is noticeable in the holocrystalline rocks, the presence of a zone of mica is no safe indication of reaction. The peculiar pegmatitic zones around the enstatite recorded by Carvill Lewis†† were not noticed in the slides of the Survey collection. Possibly the structures were fragments of the holocrystalline rocks.

The brown mica often shows a resorption border of black "opacite," while the crystals have usually been considerably corroded and rounded.

There can be no doubt that the magma has risen from a great depth, from a horizon either within or below the zone of holocrystalline ultra-basic rocks. It would be out of place to discuss the mechanism of the pipes, but several interesting points might be briefly touched upon. The great density of the magma would readily account for the great number of inclusions, especially of heavy ultra-basic rocks, a fact which will also explain why peridotite boulders are so rare as inclusions in more acid lavas, that is, if we except the "olivine-knollen" of certain basalts as fragments of pre-existing rock. The intrusive mass would become crowded with foreign fragments, and the rapid cooling and movement would produce a brecciated structure.

The breaking-up of the holocrystalline rocks would be more complete in the large pipes, for churning movements would take place on a much larger scale than in the small pipes and fissures. This would explain why such large lumps of garnet, ilmenite, chrome-diopside, mica, etc., are found in the "blue-ground" fissures and so rarely in the larger pipes. Perhaps, too, this may account for the scarcity or complete absence of the diamond in the smaller pipes and fissures.

(6) *Alteration of Kimberlite.*—The changes which have affected Kimberlite to a greater or lesser degree, and which are less pronounced in hardibanks, may be viewed from two aspects:—

(*a*) Chemical and mineralogical changes.
(*b*) Mechanical changes.

(*a*) The alteration of the various minerals has been recorded by numerous observers, the most complete account being that by Carvill Lewis. It is sufficient, therefore, merely to note that the olivine and enstatite have become partly or wholly hydrated with the formation of serpentine, while the diopside has given serpentine and a very little calcite. Carvill Lewis regarded the calcite as being possibly largely due to the alteration of melilite; this may or may not be the case.

†† Carvill Lewis. *loc. cit.* p. 18.

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Various zeolites have been formed, chief among which are natrolite and apophyllite. Barytes is often a constituent, while pyrites has crystallised in the blue-ground, and is accompanied by nodules of marcasite. At the surface the yellow-ground has completely decomposed into a pale yellowish-green rock seamed with veins of calcite, and sometimes carrying a small amount of opaline silica and oxide of iron.

(*b*) The mechanical effects depend upon the increase in bulk of the breccia due to the partial or complete serpentinization of the olivines, etc. The increase in volume accompanying the alteration of olivine is roughly 30 per cent., that of enstatite 18 per cent., and that of diopside 37 per cent.

Carvill Lewis estimated that about one-half of Kimberlite consists of serpentine (more accurately 45 per cent.); from an analysis given in Rosenbusch‡‡ the proportion is 46 per cent. In certain varieties this figure will not be quite so high.

Assuming a value of 45 per cent. and an average co-efficient of expansion of 30 per cent., the increase in bulk of the material in passing into the stage which we know as blue-ground will be therefore 13½ per cent. Now, the material is confined by walls of hard rock, and the chief way in which relief will take place will be in an upward direction. In consequence the extension of a column of the material will be about 13½ per cent., representing an upward movement of 135 feet per thousand feet. Even assuming that the mass expands equally in all directions, the longitudinal extension of a column will be 4½ per cent. It is reasonable to suppose that the degree of serpentinization will diminish with depth, but, nevertheless, the vertical movement in a column several thousands of feet in height must be considerable.

This explains a unique feature in the Kimberlite occurrences, namely, the turning up of the strata along the edges of pipes or fissures. In all other volcanic necks the strata almost invariably dip towards the axis of the pipe.

The friction between the country rock and the gradually expanding body of Kimberlite is shown by more or less vertical striations and groovings on the walls of the pipes; sheets of calcite formed at the junction frequently show casts of the slickensides.

Owing to differences in the degree of serpentinization, the contents of the pipes have suffered differential expansion, a brecciated structure has been produced, and the blue-ground is traversed by numerous slips and surfaces of shear. It is even possible that a mine may become separated into distinct compartments, each characterised by a different kind of "blue" and each extending vertically downwards. According to Moulle,*

‡‡ H. Rosenbusch. Elemente der Gesteinlehre, 2nd edition, p. 169, Stuttgart, 1901.

* A. Moulle. p. 62.

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the Kimberley mine was divided into 15 distinct compartments, separated from one another by narrow "greasy slips," while the existence of poor or barren portions of the blue extending vertically downwards to unknown depths lends further support to this view.

In passing through the Karroo shales large masses seem to have been wedged off from the walls by the expanding material while the Kimberlite has been forced into cracks and joints in the strata.

In the case of dykes which have solidified underground it is even possible that during alteration a certain amount of expansion has taken place upwards, and that the dyke has forced its way through soft strata for a certain distance long after volcanic action had ceased.

A most remarkable property of the blue-ground is its tendency to crumble and pulverise after having been exposed to the weather for a short period. Some portions refuse to disintegrate, and have been given the name of 'hardibank." As yet no one has been able to give any explanation as to the cause of the remarkable differences between the two varieties of Kimberlite. It is certainly true that in hardibanks the constituent minerals are often in an extremely fresh state; nevertheless, the groundmass has been entirely converted into serpentine.

(7) *The Diamond.*—Diamonds have been found crystallised in the garnets of an eclogite from the Newlands mine,† as well as in single garnets from Jagersfontein and the Driekopjes‡ and from the Wesselton mine, while it has also been found embedded in olivine.†† It is interesting to note that the chrome-diopside of an eclogite from Jagersfontein included some foliated graphite.‡‡

So far the only rock which has actually been proved to contain the diamond as an original constituent in South Africa is eclogite. At Kimberley Mr. Gardner Williams had about 20 tons of peridotite boulders crushed and jigged, but no diamonds were recovered. Eclogites are almost unrepresented at Kimberley, and the boulders must have been almost entirely lherzolites. Although this can hardly be considered conclusive, it tends to support the view that the diamond is not a constituent of a lherzolite. Neither is the presence of diamond embedded in olivine decisive, for on the hypothesis which I have advanced the olivines may have been formed from the ultra-basic magma around a crystal of diamond derived from a shattered eclogite.

The high proportion of pipes and fissures in which the diamond is either extremely rare or else absent altogether shows that the parent rock of the diamond is very sparingly and un-

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† T. G. Bonney. Geol. Magazine, p. 301, 1899.
‡ H. Harger. Trans. Geol. Soc. S. A., Vol. VIII., p. 133, 1906.
†† Gardner F. Williams in "Science in South Africa," p. 329, 1905.
‡‡ H. Harger. *loc. cit.*, p. 131.

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evenly distributed in the earth's crust. Since in nearly all these mines boulders of lherzolite or other variety of peridotite are commonly to be found, we have a further support to the view that the diamond has not crystallised in an olivine-bearing rock.

The typical eclogite is a dark, heavy rock, composed of garnet and chrome-diopside, together with sometimes a small amount of quartz, cyanite, mica, spinel, and more rarely felspar and the diamond. By the addition of olivine and enstatite it becomes a lherzolite, but such transitional types are not common, and there is a possibility that the eclogite is by no means closely related to the peridotites with which it is found. Firstly, the percentage of silica is so much higher, 53·75 per cent. in the case of a sample from Jagersfontein,¶ while it is deficient in magnesia; in the example just referred to it is just under 10 per cent. The diopside being rich in magnesia, the garnet will have to be a variety poor in magnesia, and not pyrope, such as is present in the lherzolites. The mica, too, is rather different from the usual variety.

Secondly, the occasional presence of cyanite—possibly, too, of corundum (sapphire)—allies it to the granulites, a view strengthened by the various types of granulitic rocks obtained from the Silver Dam pipe of the Sutherland Division.|| The discovery of basic granulitic rocks, some exhibiting points of resemblance to the eclogites, as inclusions in the granite of the Mafeking Division||||, and representing rocks which have been enveloped and metamorphosed by it, suggest a similar manner of origin for the eclogites included in kimberlite, so that the eclogite might be a completely metamorphosed rock. Deep down in the crust of the earth the granite will be succeeded by ultra-basic rocks, and the hornblende of the inclusions will be replaced by a pyroxene.

Of no small interest is the peculiar fact that occasionally diamonds are found which either penetrate or enclose one another. Such cases are rare, but in the collection from the De Beers Mines there are several examples of diamonds, each of which encloses a smaller octahedral stone. In one specimen the faces of the included stone are coated with a film of black crystallised carbon; in another, described by Mr. Gardner Williams,† there was a considerable space between the inner and outer stones, and which was filled with apophyllite. This mineral has probably been derived from without, and has been introduced into the space through a crack. The inner stone is somewhat yellower than the others, and thus of a different quality.

¶ E. Cohen. Neues Jahrbuch, p. 867, 1879. Stuttgart.

|| Ann. Rept. Geol. Comm. for 1903, p. 54, and Trans. S. A. Phil. Soc. Vol. XV. p. 68, 1904.

|||| Ann. Rept. Geol. Comm. for 1905, p. 210.

† Science in South Africa, p. 327, 1905.

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These examples show that in certain cases the growth of the crystals of diamond has proceeded in two distinct stages; such a phenomenon is not unusual in the process of crystallisation of certain minerals in rocks, *e.g.*, zircon.

It is to be hoped that the intergrowths of the diamond with garnet and other minerals will be more closely studied in the future, for one can hardly doubt that much information will be obtained in this way. In addition, more will have to be known about the ultra-basic inclusions of kimberlite, especially in regard to the characters and mode of origin of the eclogites, before the origin of the diamond can be satisfactorily made out.

(8) *Age of the Occurrences.*—That the pipes and fissures are later in age than the Karroo dolerites is clear, and they thus represent the latest phase of volcanic activity in Central South Africa. The dolerites in turn cut the Stormberg lavas, and must be either Jurassic or Lower Cretaceous. If we can correlate the melilite-basalt pipes at Sutherland with a similar intrusion in the Uitenhage (Neocomian) beds at Spiegel River (Heidelberg, C.C.), then the occurrences of kimberlite must be considered of *post-Neocomian* age. This question has been discussed more fully elsewhere.*

IV. PETROLOGICAL DESCRIPTION OF MATERIAL FROM THE PIPES AND FISSURES.

A. Holocrystalline Basic and Ultrabasic inclusions in the Blue-ground.

1525. *Gabbro.—Wimbledon, south of Kimberley.*—Dark coloured rock with blackish-green to bronze-coloured crystals of diallage.

In these sections there are areas of pale greenish diallage set in a fine-grained aggregate of prisms and granules or zoisite with some quartz, calcite and chlorite. The groundmass is evidently a much altered plagioclase felspar (saussurite).

1565. *Garnet-cyanite rock.—Frank Smith Mine.*—In this section, large grains of clear garnet, small crystals of almost colourless cyanite, which seem to be replaced in part by quartz, calcite, and mica. The groundmass consists of a clouded rather indefinite aggregate, probably in great part of colourless felspar and calcite, and which seems to have been produced by the alteration of plagioclase.

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* A. W. Rogers and A. L. du Toit. Trans. S. A. Phil. Soc., Vol. XV, p. 81, 1904.

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The rock differs somewhat from the cyanite-garnet rock of the Roberts Victor Mine, described by Prof. R. Beck.*

1572. *Eclogite.—Newlands Mine.*—A medium-grained rock composed of dark blackish green pyroxene and resinous-looking garnet, sp. gravity, 3·23.

The thin section shows pale greenish almost colourless diopside, which has altered in places to a fibrous product probably an amphibole. The garnets are large, full of cracks, and somewhat dusty.

Biotite mica is present in the spaces between the two minerals and is intergrown with the diopside and ramifies in little veins through the garnet. It is a rather unusual variety, having a pleochroism from brownish green and pinkish to colourless.

There are a few little granules of iron ore and a little calcite.

1536. *Eclogite.—Bultfontein Mine.*—A very handsome rock, composed of bright green diopside, pink garnet, and dark mica. Sp. gr., 3·25.

In thin section shows pale green diopside, altered in certain places to greenish serpentine which encloses rhombs of calcite. Cracked pink garnets and a biotite which is intergrown with the diopside and garnet.

1561. ——— *From a fissure near Llanover (H.V. 61), Barkly West.*—A dull blackish rock with spangles of black mica. Sp. gr., 3·05.

The thin section shows this rock to be of a most unusual type. The augite is in beautifully idiomorphic crystals sometimes very much elongated. It is pale in colour and towards the ends of the prisms it passes insensibly into deep green aegerine; this is sometimes also the case along the prism faces.

The augite is altered in a patchy manner to a fibrous product, which in turn has changed to serpentine and calcite. The aegerine forms small crystals in addition, and both these and the large augites are bordered by a fringe of needles and narrow prisms of brownish-green acmite arranged either normally to the crystal faces or more commonly making a small angle with them. Bunches of these acmite prisms are scattered through the groundmass, and are here and there enclosed by a yellowish green mineral which has optical properties similar to those of acmite except in its weaker pleochroism. It is probably a closely related mineral.

Deep reddish-brown biotite is abundant in large plates, and commonly encloses fairly big crystals of apatite. The biotite must have been one of the first minerals to crystallise as the augite has been moulded upon it.

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* Proc. Geol. Soc. S. A., p. xlviii., 1906

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The colourless groundmass consists of a mixture of quartz and unstriated felspar which, from the presence of aegerine and acmite is probably an orthoclase. The groundmass is crowded with tufts and needles of acmite, abundant large granules and aggregates of sphene, some ilmenite, and crystals of a colourless mineral with high refractive index and negative double refraction.

The rock shows a great resemblance to the theralites, but nepheline could not be recognised with certainty; the abundance of aegerine and acmite, however, indicate a high soda content. From its structure it may possibly be grouped with the camptonites.

1529. *Mica rock.—Taylor's Kopje, Kimberley.*—A well-foliated rock composed almost wholly of a yellow brown mica with weak pleochroism and with a small biaxial angle. Embedded in the mica are small diopsides, seldom showing any crystal edges, and a few grains of sphene.

1539. *Mica rock.—Bultfontein Mine.*—Yellow brown mica with reverse pleochroism, thus differing from the preceding rock. A few grains of diopside and some magnetite. Sp. gr., 2·80.

The rock has been affected by pressure, and is traversed by lines of serpentinous material; the mica crystals are bent, and show an extremely well-developed brachypinacoidal cleavage.

1554. *Enstatite-mica-diopside rock.—Kimberley Mine.*—A well-foliated rock traversed by planes rich in mica.

There are numbers of small diopside grains which are usually enclosed by enstatite or mica; sometimes there is an intergrowth of mica and diopside.

The enstatite shows along edges and cleavage cracks an alteration to bastite and serpentine, while the diopside is in places altered to diallage.

There are two varieties of mica: one a darker yellow brown mica with normal pleochroism which commonly occurs in small hexagonal flakes, and the other a lighter coloured mica with reverse pleochroism which forms large plates having ragged outlines.

Frequently these plates are surrounded by a rim of normal mica; sometimes there is an intergrowth of the two varieties. The mica includes or is attached to sphene and ilmenite.

1517. *Olivine-diopside-mica rock.—De Beers.*—A dark rock traversed by more or less parallel bands rich in mica. Sp. gr., 3·00.

Olivine sometimes in large areas but more commonly in somewhat rounded granules; diopside, which has grown round and enclosed the olivines.

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Mica in large plates enclosed both by the olivine and diopside, and showing reverse absorption. In a couple of places it is intergrown with normal mica.

Ilmenite forms small granules enclosed by all the other minerals.

1524. *Olivine-mica rock.—Wimbledon, near Kimberley.*—A dark compact rock with small reddish areas. Sp. gr., 2·86.

In thin section is found to be composed chiefly of olivine, which is capriciously altered, sometimes over large areas to a brownish or greenish serpentine, bluish black along the cracks and cleavages of the mineral. The mica occurs in large aggregates of small plates, and shows reverse absorption and rather weak double refraction.

Included both by the mica and olivine are narrow indefinitely terminated prisms of a colourless mineral, showing a well-defined longitudinal cleavage and an irregular transverse parting. The refractive index is high, double refraction moderate, and the angle of extinction has a maximum value of 30°.

Taken in conjunction with its other optical properties the mineral must be cyanite; its unusual presence in peridotite may perhaps be due to the incorporation of foreign material by an ultra-basic magma.

There are small peculiar ramifying growths of limonite with the mica and cyanite, also a few grains of magnetite.

1540. *Olivine rock.—Bultfontein Mine.*—A black fine-grained rock which can be readily cleaved; shows little patches of mica and small green chrome-diopside grains. Sp. gr., 2·75.

In thin section the great bulk of the rock is found to be composed of olivine. Owing to the extremely crushed nature of the rock the olivine is found to be granulitized, and different parts of what was originally one crystal are now differently oriented. Alteration has proceeded along the cracks, and we thus find a regular mosaic of olivine granules of more or less uniform size set in a groundmass of pale greenish serpentine, in fact the rock shows features very similar to those in a fine-grained quartzite. A crystal of enstatite has been similarly granulitized but the shattering and serpentinization have not been so great. The diopside grains being so small have not been much affected. Minute grains of magnetite are present, almost entirely in the enstatite.

1530. *Olivine-enstatite rock (Saxonite)—Taylor's Kopje, Kimberley.*—A coarse-grained rock composed of olivine and enstatite. The former is in large crystals, and shows a good cleavage and strain shadows; it is only slightly altered along cracks. There is a small amount of pale yellow mica in which are embedded grains of magnetite, and a few small granules of chrome-diopside.

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1534. *Olivine-enstatite rock (Saxonite).—Dutoitspan Mine.* —A dark coarse-grained rock in which the enstatite has a platy structure; towards the exterior of the boulder the bastite cleavage is more strongly developed and the crystals have a reddish metallic appearance. Sp. gr., 2·87.

In thin section the olivine exhibits a remarkably fine cleavage and is altered along cracks and cleavages to yellowish serpentine, which has in places a deep bluish tint. The enstatite has a pale brownish appearance due to the fibrous structure. A few flakes of mica are present. There are peculiar ramifying or graphic intergrowths of limonite with the mica and olivine.

1538. *Olivine-enstatite rock (Saxonite)..—Bultfontein Mine.* —A coarse-grained rock in which the enstatites are sometimes more than half-an-inch across.

The thin section shows olivine much serpentinized and a very fibrous brown enstatite with a very feeble pleochroism. Like the preceding rock, there are intergrowths of limonite and olivine.

1535. *Olivine-enstatite rock (Saxonite).—Dutoitspan Mine.* —A dull black rock containing bright platy enstatites sometimes over an inch across.

It is very much like 1538 but contains small biotites, mostly in well-formed hexagonal plates, which are collected along the lines of junction of the enstatite and olivine.

1504. *Olivine-enstatite rock (Saxonite).—De Beers Mine.*— A very handsome dark green rock with bronze-coloured brilliant enstatite (bronzite) crystals from an eighth to a quarter of an inch across, and from which the mica can only be distinguished with difficulty. Sp. gr., 3·00.

In thin section the most interesting mineral is found to be the enstatite. It is deep yellow-brown in colour except in a few places where it is still quite fresh. The colour is due to minute elongated plates of an iron ore which are arranged along one set of cleavage planes.

One section is cut at right angles to the plane containing the inclusions and to the vertical axis of the crystal; the inclusions are thus seen on edge as parallel rows of disconnected lines, and acting on light like a diffraction grating give a blue grey colour to the enstatite instead of a yellow brown.

Pale yellowish feebly pleochroic mica borders the enstatite; one crystal shows a ramifying growth with limonite.

1502. *Olivine-enstatite-garnet rock.—De Beers Mine.*—A medium-grained green rock. Sp. gr., 3·19.

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Enstatite in elongated crystals with rounded ends and with fibrous serpentinous borders surrounded by olivine. The latter is traversed by lines of crush indicated by bands of granulitic olivine sometimes forming a mosaic. The olivine includes small idiomorphic crystals of a nearly colourless mineral having the optical properties of epidote. A few garnets are represented and are much clouded and almost opaque; seen by reflected light they are dirty-white in colour.

There are several areas of yellowish green serpentine enclosing crystals of a pale biotite, probably of secondary origin.

1516. *Olivine-enstatite-garnet rock.—Bultfontein Mine.*—A deep black rock with greyish crystals of enstatite, small garnets, and little bright green grains of chrome-diopside. Sp. gr., 2·98.

In thin section the only feature worth noting is the dark bluish black zone of colour bordering the serpentine along the cracks of the olivine. The colour is due to the separation of magnetite in a finely-divided form, which acts as a diffraction grating upon the transmitted light.

1506. *Olivine-enstatite-diopside-garnet rock (Lherzolite).—Bultfontein Mine.*—In this rock the grains of the different minerals approach one another more nearly in size than in any of the other holocrystalline rocks described, and thereby a medium-grained granulitic rock is produced. The chrome-diopside has a diallagic habit in places, and is altered along cracks to yellow serpentine.

The serpentine produced from olivine has often, as in 1516, a dark blue colour due to dispersion.

The garnets are dusty and cracked, but rather large, and are distributed irregularly through the rock.

1514. *Enstatite-olivine-diopside-garnet rock (Lherzolite).—De Beers.*—Enstatite very abundant and very fresh; olivine less in quantity than is usual; large garnets which are clear and colourless, and round which some mica has formed. Pale greenish chrome-diopside has formed in the spaces between the other minerals. In one case it shows twinning.

1513. *Enstatite-diopside-olivine-mica rock.—De Beers.*—As indicating the extraordinary variation of the peridotites it may be remarked that this section and the preceding one have been cut from opposite ends of the same hand specimen.

The portion yielding this section is a dark greenish-grey mottled rock through which are distributed aggregates of mica, which contain none of the other minerals of the rock and which have sharply defined outlines. They are circular or oval in section and have a diameter of from one to three eighths of an inch.

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In thin section these patches are formed of interlocking plates of a nearly colourless mica commonly enclosing, especially towards their centres, minute crystals of iron ore. The edges of the patches are either bordered with a narrow band of serpentine calcite and small pyroxenes, or else the mica becomes intergrown with the diopside, sometimes ophitically.

The chrome-diopside has a pale yellowish-green tint, and occurs both simple and twinned; commonly the crystals are small and interlocking.

The enstatite and olivine are in rather large crystals.

1537. *Olivine-enstatite-diopside-garnet rock (Lherzolite).—Bultfontein Mine.*—The olivine has been generally much crushed, and polarises frequently as a mosaic. The narrow veins of serpentine which traverse this mineral have often a dull blue colour; under a high power there is seen a narrow central axis from which extends outwards a fringe of dark thread-like bodies formed by rows of minute magnetite granules. These structures may best be likened to the midrib and venation of ferns.

The enstatite is clear but sometimes considerably altered to colourless serpentine. The chrome-diopside is pale yellowish-green in sections, and is much altered along the cleavages similarly; the absence of calcite indicates that the diopside contains no lime.

The garnets are nearly colourless in section; in the hand specimen they are beautifully smooth and often well rounded.

1505. *Olivine-diopside-garnet rock.—Bultfontein Mine.*—A dull green rock with small amethystine garnets. Sp. gr., 2·98.

The olivine is granulitized in certain places.

The diopside is a colourless variety which is intergrown with a little chrome-diopside. A small amount of enstatite is present. Garnets are abundant and are small, well-rounded, and dusty; they have dark borders.

1515. *Olivine-diopside-garnet rock.—Bultfontein Mine.*—A dark green rock with large well-rounded deep red garnets. Sp. gr., 2·90.

Olivine and pale green almost colourless diopside, both much altered to pale serpentine. The garnet and sometimes the diopside is surrounded by a very narrow zone of yellow brown mica, which there is no reason to believe to be other than original.

1507. *Enstatite-diopside-olivine-mica rock.—Bultfontein Mine.*—A greyish rock with plates of brown mica and grains of bright green chrome-diopside. Sp. gr., 3·11.

Enstatite and a colourless diopside form the great bulk of the rock; olivine is not abundant. Pale green very weakly pleochroic chrome-diopside and a yellow mica are present in about

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equal proportions. The chrome-diopside and olivine were the first minerals to crystallize and were followed by the mica and the two pyroxenes.

Summary of the characters shown by the Peridotites.—The peridotites consist of different combinations of the minerals olivine, enstatite, diopside, mica, and garnet, and seldom contain more than a very small amount of iron ores. The rather low densities which they possess may be accounted for partly by alterations which have affected the constituent minerals and partly by the small iron content of the rocks. The olivine, enstatite, and diopside are evidently nearly pure magnesian silicates, and through hydration produce nearly colourless serpentine with but a trace of calcite and magnetite. The densities of the minerals will therefore be lower than those of the corresponding ferriferous varieties.

The rocks exhibit even in hand-specimens great variation in composition, while very often they show marked mineral banding and are foliated.

In texture they vary from medium to extremely coarse-grained rocks; the olivines do not attain any great size, but lumps of enstatite and diopside the size of a man's fist are not uncommon in the blue ground, and garnets far bigger even—Graichen mentions one from the Newlands Mine about 12 inches in diameter.

The rocks show the effect of earth-pressure and the olivines are not infrequently granulitized; the enstatite and diopside have not been affected to the same degree. In one specimen (145 l.) a large crystal of enstatite has been sharply folded and is traversed by small thrust-planes.

The source of the peridotites must lie far below the granite. The latter being a well-foliated gneissic variety, it is natural to suppose that the crushing and shearing of the ultra-basic holocrystalline rocks has been accomplished by the same forces which produced the foliation in the granite. It is nevertheless possible that the foliation and mineral-banding in the peridotites are due to causes which operated at a still more remote period in geological history.

B. Kimberlite.

Such excellent accounts of the petrological character of the blue-ground have been given by Carvill Lewis and Prof. Bonney that in the following pages only special points in the different varieties of Kimberlite will be noticed. The majority of the sections have been taken from hardibanks on account of the fresher state of the constituent minerals.

1527. *Hard-blue.—Taylor's Kopje, Kimberley.*—Olivine very fresh, often in finely idiomorphic crystals, showing macrodomes and pinacoids; usually serpentinized on the outside the serpentine so formed containing little needles of rutile. The

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crystals of olivine in the groundmass are frequently so minute as to give the rock a porphyritic appearance. Mica both normal and abnormal, usually intergrown; borders bleached and possessing rims of opacite. Some diopside. Groundmass of serpentine, ilmenite, perofskite, etc. Inclusions of peridotite and dolerite.

1518. *Hard-blue.—Kimberley Mine.*—Large olivines, diopsides, enstatites, and fragments of peridotite, all with rounded outlines, and which are set in a groundmass crowded with tiny olivines mostly showing crystal outlines. Serpentine, perofskite, ilmenite, etc.

1501. *De Beers Mine.*—A piece of fine-grained blue, traversed by a two-inch vein of coarse-grained rock; in the thin section the junction between these two varieties is very sharp.

The fine-grained rock contains porphyritic olivines and slightly-rounded or else angular pieces of olivine, enstatite, diopside, and corroded micas set in a dense groundmass crowded with granules of iron ore; perofskite is not abundant.

The coarse-grained portion is crowded with fragments of shale, grit, dolerite, peridotite, etc., and includes some finely idiomorphic olivines. That these last have been derived from the fine-grained rock is quite evident, for they are frequently surrounded by a narrow zone of the dark groundmass characteristic of the latter, while angular and rounded portions of the fine-grained rock are abundant The groundmass of the coarse-grained portion is light in colour and rich in calcite.

Clearly the fine-grained rock represents the original magma with its included fragments derived from the deep-seated holocrystalline rocks; through brecciation and the consequent mingling with fragments of shale, etc., the coarse-grained variety, approaching more nearly in character the usual type of Kimberlite, has been produced.

1099. *Soft-blue.—Kimberley.*—The specimen shows somewhat similar features to the preceding rock. Many of the olivines show an attached film of a fine-grained serpentinous material containing ilmenite and perofskite, the whole being enclosed by a ring of dark matter.

1077. *Vein in blue-ground.—1,200 foot level, De Beers Mine.*—An extremely fine-grained rock crowded with finely-idiomorphic little olivines and diopsides which are perfectly fresh and unaltered. The groundmass consists of colourless serpentine, granules of ilmenite and perofskite and a few irregularly-shaped flakes of mica.

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The rock was very probably originally a glassy peridotite (*limburgite*), but the glass has now been hydrated with the formation of serpentine and a little calcite; it seems to approach most nearly in character to the "generative-magma" of Kimberlite.

1162. *"Snake rock."—Dyke in porphyry at 1,720 foot level, De Beers Mine.*—Very much like ordinary blue-ground, but the minerals are much less altered. Olivine, enstatite and diopside are abundant, the first named being finely idiomorphic as a rule; mica of both varieties.

Foreign fragments are present, but not abundant.

The "Snake-rock" is a slightly later intrusion, and cuts vertically through the blue-ground of the mine.

1532. *Vein in blue-ground.—Dutoitspan Mine.*—Idiomorphic and angular olivine and angular or rounded diopside, enstatite and fragments of peridotite embedded in an extremely dense groundmass.

The olivines are altered along cracks and are surrounded by an inner narrow zone of radially arranged fibrous chrysotile enclosed by a thin shell of colourless serpentine.

A most notable feature in regard to the olivine is the abundance of needles of rutile in it lying in positions more or less parallel to the crystal boundaries. The rutile is as abundant in the unaltered as in the serpentinized portions of the olivines, and is, therefore, not confined to the latter, as believed by Carvill Lewis.†

Micas of both varieties are well represented and are always surrounded by deep black borders.

1548. *Vesicular blue-ground.—Dutoitspan Mine.*—A dark blue very fine-grained rock devoid of foreign inclusions and full of cavities lined or filled by calcite. These vesicles are sometimes arranged in rows, and give the rock a banded appearance.

In thin section the minerals of the rock are olivine and diopside with subordinate enstatite and mica, the two first-named being usually idiomorphic. The groundmass contains a good deal of serpentine, rhombohedra of calcite, and abundant little prisms of apatite. By treatment with strong hydrochloric acid these minerals are removed and there remains a pale, almost colourless, isotropic unstainable substance containing minute dark granules, iron ores, perofskite, etc.

† Carvill Lewis. p. 17.

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1510, 1511. *Hard blue.—St. Augustine's Mine, Kimberley.*—Olivine very abundant, enstatite and diopside subordinate. The mineral grains are sometimes beautifully rounded, but the olivine has a tendency to idiomorphic outlines. Abundant tiny olivines in the groundmass. The micas are much altered and replaced by aggregates of chlorite, a nearly colourless mica, and carbonates.

1522. *Hard blue.—Wimbledon, near Kimberley.*—The olivine and possibly enstatite and diopside are completely replaced by a perfectly clear and colourless serpentine. Carbonates rarely accompany the latter, but the presence of a small amount of iron is shown by very minute specks of iron oxide.

The groundmass consists of a small amount of serpentine with a large quantity of calcite, and it is crammed with minute micas in well-formed hexagonal plates and with small apatite prisms. The micas show a core of the normal and shell of the abnormal variety. Ilmenite and perofskite are not so abundant as usual.

1543. *Hardibank.—Kamfersdam Mine.*—An interesting feature about this rock is its dark green colour, which is due to plates of a weakly pleochroic chlorite, evidently an altered mica.

Perofskite is most abundant, and in many cases includes a core of titanic iron, sometimes one of sphene. This is not a unique feature confined to this rock alone, but is shown in every slide of kimberlite.

Where the grains of ilmenite are large they are surrounded by a ring of little perofskite crystals. The granules of ilmenite and sphene are frequently surrounded by a shell of highly refractive and weakly polarising mineral which varies from colourless to pale bluish or yellowish; it is commonly enveloped by iron oxide. This mineral seems to be an alteration product of the titanic iron; possibly it is a variety of perofskite, for it is sometimes associated with that mineral and, like it, a single grain is found under polarised light to consist of several individual crystals. This alteration product of ilmenite is abundant in certain varieties of kimberlite.

1555. *Hard blue.—"Mount Ararat," Dutoitspan Mine.*—A rather altered rock with numerous enclosures of shale, diabase, dolerite, and peridotite. The groundmass contains abundant granules of ilmenite altering to the colourless mineral mentioned above. The crystals of the latter are large, show square or hexagonal outlines, and have a rather wide border; granules of perofskite are sometimes frequent in the colourless alteration mineral.

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There are numerous narrow lath-shaped areas of calcite which represent pseudomorphs after some unknown mineral, also minute needles of apatite.

C. On an Abnormal Mica.

The presence of a pale magnesian mica with reverse pleochroism has been remarked upon as occurring both in the ultrabasic rocks and in the blue ground. It is so abundant—nearly every other slide of kimberlite containing one or more flakes—that it is extraordinary that it should have hitherto escaped observation and comment.

Except for its action on polarised light this variety does not differ from the normal mica in the blue ground. It is found both in large plates and in minute little scales, and sometimes forms a nearly pure mica rock. *Both* micas sometimes show a remarkably brachypinacoidal cleavage sometimes developed to such a degree that a cleavage flake can be broken up into little rectangular prisms, and in extreme cases the mineral becomes almost fibrous. Both varieties are very nearly uniaxial; the optic axial plane is the plane of symmetry and the mica is of the second order. The extinction angle, measured from the trace of the basal cleavage, has a value from 0° up to 4°. Both micas have a very pale tint, and the pleochroism is from colourless to light yellow brown, but sometimes the change is hardly noticeable. They are probably intermediate between the biotite and phlogopite micas.

In the abnormal mica the maximum absorption occurs when the basal cleavage is at right angles to the short-diagonal of the nicol-prism; in basal sections there is no appreciable change of colour. The absorption scheme is

$$\mathfrak{a} > \mathfrak{b} \lesseqgtr \mathfrak{c}$$

It frequently occurs intergrown with normal mica, and invariably has a lower double-refraction, commonly about two thirds of the value for the latter. In the great majority of cases the normal mica forms a zone around the abnormal variety; in section 1522 this order is reversed and little crystals of normal mica are surrounded by a shell of abnormal, the latter having a more pronounced pleochroism—from brown to a very pale green.

A mica of similar abnormal character was recorded several years ago in melilite-basalt from a pipe on Matjes Fontein (Sutherland),* and constitutes another point of resemblance between the pipes containing melilite-basalt and those filled with kimberlite.

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* Ann. Rept. Geol. Comm. for 1903, p. 50.

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The micas in the blue-ground have in part been derived from the breaking up of the ultra-basic rocks, the plates being frequently bent or attached to enstatite or some other mineral.

That some of these micas have originated from the magma is shown in several ways. They often occur in little plates with regular hexagonal outlines, and are almost devoid of inclusions. There can be no doubt that the micas of the melilite-basalts have formed out during the crystallisation of those rocks.

In slide 1522 there is a fine example of the regeneration of a fragment of mica derived probably from the shattering of a granite. The core is a bent flake of slightly dusty pleochroic biotite, it is surrounded by a pale normal mica, and that in turn by a shell of the abnormal variety. The growth of micas in the magma can very frequently be inferred by the fact that a ragged core of normal or abnormal mica has had its crystal outline reconstructed, the new material being a nearly colourless variety. Embedded in this shell, usually at the junction of the two varieties, are abundant inclusions of ilmenite, perofskite and apatite, minerals with which the groundmass of the rock is crowded. Some of the crystals with "bleached-borders" may have acquired those characters through a secondary growth of mica.

The abnormal mica is not confined to the blue-ground of the mines described in this Report; I have found it also in material from the Jagersfontein, Premier (Transvaal) and Monastery Mines (O.R.C.), and it is probably widely distributed.

Abnormal biotite mica has been recorded from other parts of the world,† and a slide (1094) in the Survey collection of monchiquite rock from India shows an intergrowth of normal and abnormal biotite.

No analysis was made of this abnormal mica in order to determine whether it differs in chemical composition from the normal variety, but it is somewhat denser, the specific gravities of the two kinds being 2·796 and 2·731 respectively.

† C. Hintze. Handbuch der Mineralogie, II., p. 546.

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SECTION III.

THE DIAMONDIFEROUS GRAVELS.

The diamond-bearing gravels of the Vaal River Valley have received a considerable amount of attention by geologists from a very early period, yet practically all our information consists of the somewhat brief descriptions of the "diggings" by Stow, Shaw, Cohen, Moulle, Dunn, Boutan, and Coe.

The gravels occur at intervals on both banks of the Vaal River, sometimes at a considerable distance from the river-bed and usually in more or less disconnected patches. Such gravelly deposits have been worked from Christiana, in the Transvaal, as far south as the junction of the Vaal with the Orange River. Gravels occur as well on the Orange and Riet Rivers, but are sparingly diamondiferous. There are no deposits of this nature in the Harts River Valley.

The gravels are situated at various levels as well as at varying distances from the river, and though they form a number of fairly distinct terraces, it is not always easy to determine their relative age.

In order to make clear what follows a brief account of the history of the Vaal River will be necessary.

The Vaal River at one time flowed entirely over rocks belonging to the Karroo formation—that is within the area under description. Upon deepening its channel the underlying floor of diabase and amygdaloid was laid bare, and while the river was able to excavate rapidly in certain parts of its course, such as to the north-east of Warrenton, at Riverton, Pniel, Delport's Hope, and from Schmidt's Drift down to beyond Douglas, in other places it had to cut its way through ridges of hard rock. The two most important barriers were between Warrenton and Windsorton, and again between Barkly and Sydney, but there are numerous minor ridges all along the river as well.

On the up-stream side of the barrier the rate of deepening would be far less than on the down-stream side, and hence the gravels deposited at these two points will differ in elevation above the bed of the river.

For example, at Warrenton the gravels cover a wide area between the village and the railway; the surface upon which they are deposited, though rather uneven, slopes gently towards the river, and has an altitude of from 50 to 75 feet above it. The gravels are unevenly distributed over this surface, and, therefore, form a layer of variable thickness. Little patches occur on the north bank close to Fourteen Streams Station.

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From Warrenton the gradient of the Vaal increases, and the river flows in a deep gorge cut in diabase. Little patches of gravels still remain on both sides of the river, and as one proceeds down stream their altitude relative to the river-bed increases.

Thus we find areas of high-level gravels on Waterval, Roode Dam, and Hebron, the diggings on this last farm being known as "Fool's Rush."

East of Windsorton the upper gravels are absent owing to the subsequent erosion of the soft Karroo beds. Little patches of gravel and accumulations of pebbles on the flats between Windsorton Road and Riverton Road Stations are probably relics of this terrace.

On the west of the Vaal the terrace is finely developed at Klipdam, where it has an altitude of 200 feet above the river and a distance from it of $3\frac{1}{2}$ to 6 miles. Both the diabase and Dwyka formations have been cut equally to form an even surface falling gradually to the south.

The principal tract of gravels is from a half to one and a half miles in width, and extends southwards from Klipdam for a distance of five miles. Outliers occur to the west and south-west, at Holpan, while lower gravels are being worked south of the Leicester Mine.

The continuation of the Klipdam terrace is found on Modder Hoek, about a mile from the Vaal, and forms a remarkably even slope, extending along the right bank of the river into the bend opposite Riverton. The gravels rest upon Dwyka shales and splendid sections are seen along the cliff facing the river (on Khosop's Kraal). The slope in the twelve miles from Klipdam is at the rate of 10 feet per mile.

It is evident that the Vaal has been able to cut more rapidly downwards here than to the north of Windsorton, so that the gravels at the two extremities of the layer extending from Klipdam to Khosop's Kraal are not of the same age. The Klipdam portion represents the oldest part of the deposit, while that at Khosop's Kraal is of considerably later age. The Warrenton deposits, on the other hand, cover the entire period taken for the formation of the gravel-covered Klipdam-Khosop's Kraal slope.

As the Vaal deepened its course near Windsorton, a lower bank of gravels was deposited some 50 feet or thereabouts above the level of the present river.

This terrace extends for a distance behind the village, both up and down the river, while it appears on the opposite bank, on Rietput, and carries the upper gravels of the Wedburg area. Patches of gravel also occur down stream on Krans Vogel Vlei and in the big bend on Slyp Klip North.

Just as we find a gravel slope stretching from Klipdam to Khosop's Kraal, so we have the same feature repeated just

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before reaching Barkly. The highest gravels cap a diabase ridge on Hols Dam; from this point there is an almost unbroken slope into the great loop of the Vaal, opposie Pniel, known as "The Bend."

Little patches of the oldest gravels occur at points about a mile and a half north-west, and again north-east of Barkly, and have an altitude of about 200 feet above the river-bed.

From Barkly to Delport's Hope we have a repetition of the Warrenton-Riverton section; the river has had to cut through a barrier of diabase, but beyond this ridge the soft Karroo rocks have been easily disintegrated and the older gravels removed along with them. Thus none of the deposits from Waldeck's Plant to Delport's Hope can be classed along with the older gravels, and the only record of the early history of the Vaal is found in the sand-covered gravels of Droogeveldt, adjoining the Pniel Mission land and the Kimberley divisional boundary. The locality is known as Doorn Laagte. These gravels are from four to five miles from the river and at an altitude of 300 feet, if not more, and are spread over a gently undulating surface of diabase.

Though carrying diamonds of good quality the deposits have hitherto not been worked, owing to the lack of water in the vicinity.

Still further down the Vaal, thin washes of gravels are found east of Schmidt's Drift on the farms Vogelstruis Pan and Dispute up to an altitude of about 350 feet above the Vaal.

Of the terraces between Waldeck's and Delport's the highest which we find is a little patch on the top of a kopje about one mile north-west of Longlands, 80 feet above the river; while at Sydney, on the south bank, similarly situated gravels are being worked.

The gravels at Barkly, Waldeck's Plant, Gong-Gong, Niekerk's Rush, Longlands, Winter's Rush and Delport's Hope, form a terrace on a somewhat lower level (from 30 to 45 feet above the river-bed), while similar deposits occur at intervals further down the Vaal and at varying heights, *e.g.*, Schmidt's Drift, R.25, R.23, Atherton, and on the Douglas Commonage at the location.

At Wedburg (Windsorton) and Smith's Gully (Waldeck's Plant) there are channels only recently abandoned by the river, now filled with boulders and gravel. These deposits form what are known as deep placers as the thickness of gravel is frequently considerable. The floors of these channels are sometimes smooth, sometimes full of hollows and pot-holes.

Composition of the gravels.—The pebbles composing the gravels vary considerably in size, and it may be taken as a general rule that they are smaller and of more resistant material in the higher and older terraces. They are well worn and rolled, and commonly show percussion markings and cracks. The

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agates being of a rather brittle nature frequently occur in rather angular pieces; the breaking up may be due in great part to sub-aerial weathering.

The pebbles consist of agate, chalcedony, quartz, variously coloured and striped quartzites, blue, black, yellow and brown banded cherts, jaspers and ferruginous cherts—locally known as "bantams"—lydianite and silicified wood.

The small rusty-weathering pebbles which form a very great proportion of the gravels are of extremely fine-grained quartzite.

Much of the material has travelled a considerable distance, as the banded cherts, quartzites and jaspers do not occur in the neighbourhood. Some have very probably been derived from the conglomerates of Taungs and Pokwani, but most of the material must come from the Transvaal. The agates, chalcedony and quartz are derived from the amygdaloidal lavas of the Vaal River Valley, and the silicified wood from the Karroo beds —of the Orange River Colony principally—the latter being usually in flattish pieces.

The lower gravels are crowded with boulders derived from the Dwyka conglomerate, and hence the abundance of diabase, amygdaloid, quartzite, porphyry, chert, etc. The greater number of these inclusions have not travelled very far, and were already rounded before they became incorporated in the gravels. In the deep placers such as the Wedburg (Windsorton), Smith's Gully (Waldeck's Plant), etc., the gravels consist chiefly of boulders from the Dwyka embedded in a mass of sand and pebbles. Some of these boulders attain a length of four feet and occasionally they still show striated surfaces.

Age of the terraces.—There can be no doubt that the highest gravels date back to a period when the topography was far different to that of the present day. When the oldest gravels were in process of formation the present valley of the Harts River had apparently not yet come into existence; since that period a broad valley has been excavated to a depth of over 500 feet.

In the earlier terraces I have not found any traces of palaeolithic man, but in those which are situated at altitudes of from 20 to 40 feet above the present river-beds water-worn worked implements are not uncommon.

Such occurrences have been recorded by Messrs. Johnson and Young* at Barkly West, Droogeveldt, Schmidt's Drift and Douglas, and there can be no doubt that man existed in this part of South Africa at a time when the rivers had not cut down to their present levels.

Near Barkly West, at a point nearly midway between the town and the bridge, rolled implements of diabase form no small proportion of the constituents of the gravels.

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* J. P. Johnson. Trans. Geol. Soc. S. A., Vol. IX., p. 53, 1906.

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The age of these terraces cannot be fixed palaeontologically. The remains of *Mastodon*† in a 60 to 80 foot terrace at Waldeck's Plant, indicate that these lower gravels are either contemporaneous with or later than the fossil they contain.

Source of the diamond.—The discovery of diamond pipes shortly after the establishment of the diggings at once suggested a source for the gems in the gravels, especially as they are associated with small garnets and fragments of diopside and ilmenite.

This view was strengthened by the subsequent finding of blue-ground pipes in Barkly West close to and sometimes surrounded by diamond-bearing gravels.

The great objection to this simple solution was the important fact that the river stones were found as a whole to be superior in quality to the mine stones, and to this day they realise a higher price. Moreover, the stones from each of these two sources have characters which enable experts to distinguish them from one another; I am informed nevertheless that although it is comparatively easy to pick out a few mine stones from among a number of river stones, the converse cannot always be accomplished with the same degree of certainty.

Among the river stones are diamonds of all shapes and colours, and the proportion of yellow, clouded, spotted and fancy stones seems to be almost as high as among those from the mines; nevertheless, the former are superior in brilliancy and fire. There are several mines which produce or have produced diamonds approaching very closely indeed in their quality to those from the diggings. These mines are Jagersfontein, Frank Smith, Leicester, Balmoral, and Newlands.

We have seen that owing to the continual attrition during the formation of the gravels only the hardest materials have survived, and the diamond has not escaped, in spite of its extreme hardness. Mr. Ed. Williams, an expert diamond buyer, estimates the proportion of diamonds with their edges and angles worn at from 25 to 30 per cent.; for this information I am indebted to Mr. Rees, the Inspector of Claims at Barkly West. It is not necessary to suppose from this fact that the stones have been brought from a great distance, for the following reasons:—

The wearing of the edges of diamonds is not indicative of intense attrition, for it is well known that in boring with a diamond drill the stones may be considerably worn if the pressure applied to the crown is not great enough. Secondly, wherever the slope of the terraces can be determined we find evidence of gentle gradients in the river; the stones and pebbles may not have suffered so much from transport down stream as from wear by grinding in hollows and pot-holes.

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† R. Beck. Geol. Mag. p. 49, 1906.

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The diamonds will thus come in great part from the areas which were drained by the Vaal River in times past; some of the stones may have come a distance, while others may have been derived locally. The wearing of the stones would tend to remove crystalline irregularities, etc., but the superior quality cannot be accounted for in this way alone. The invariable superiority of alluvial diamonds all the world over to the mine stones suggests that possibly the former may have been improved by prolonged exposure. Failing this, we are forced to assume that there are mines as yet undiscovered from which these superior diamonds have been derived. The many new occurrences of blue-ground discovered each year will no doubt in the near future afford more reliable data upon which to base conclusions.

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INDEX.

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Digitized by Google

Digitized by Google

S.

T.

U.

V.

W.

Z.

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